THE GROWTH OF A PLANET

EDWIN SHARPE GREW

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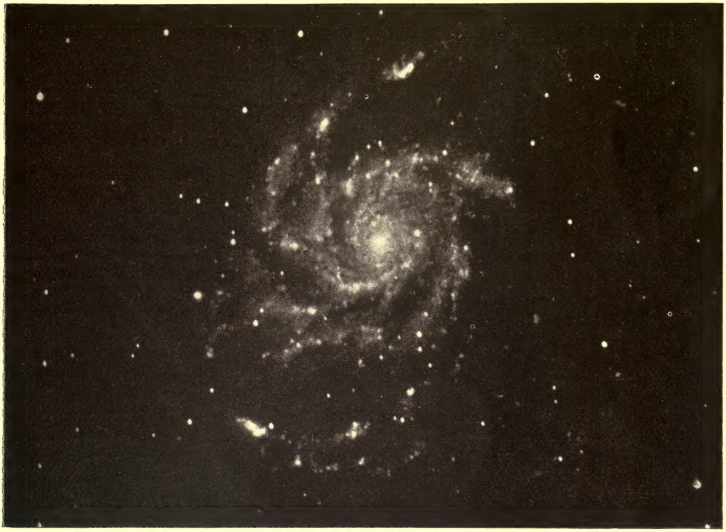
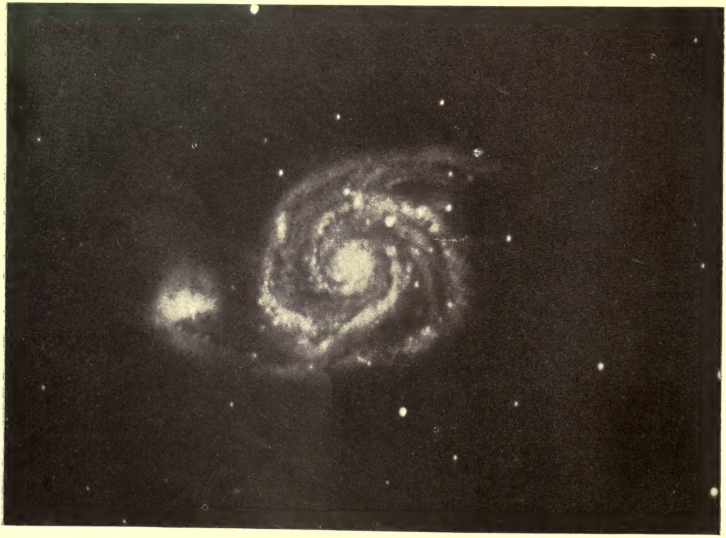


SPIRAL NEBULA SHOWING DOUBLE ARMS

(M. 101 Ursae Majoris)



SPIRAL NEBULA SHOWING DETACHED MASS

(M. 51 Canum Venaticorum)

(From Nebulæ and Clusters by J. E. Keiller)

THE GROWTH OF A PLANET

BY

EDWIN SHARPE GREW, M.A.

WITH NINE ILLUSTRATIONS AND NUMEROUS DIAGRAMS

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PREFACE

IN this volume an attempt is made to summarize and link together the modern theories which endeavour to explain the origin, the formation, and the growth of the units of the Solar System. The greater number of these theories, astronomical, physical, geological, geographical, and biological, have been bequeathed to science from the Nineteenth Century; but there are hardly any on which the ideas and discoveries of the last twenty years have not thrown light: and there are some which belong exclusively to the Twentieth Century. The plan followed by the author has been that of dealing with the Sun and the Earth's neighbours among the Planets from the point of view of astronomical and physical theory: and thenceforward of following the course of geological and biological growth on the one planet, the Earth, of which there is any intimate knowledge.

In so wide a subject the treatment must often be of an extremely summary character: and the author has kept in view the aim of interpreting clearly and accurately the theories with which he has had to deal rather than that of criticising them. Accuracy would of itself have been difficult of attainment but for the help he has received from the criticisms and sugges-

tions of authorities on the subjects dealt with. He wishes, therefore, to acknowledge with the most sincere gratitude the help given to him by Mr. E. Walter Maunder, F.R.A.S., of the Royal Observatory, Greenwich; by Professor W. Watson, D.Sc., F.R.S., of the Imperial College of Science; by Professor F. W. Oliver, D.Sc., F.R.S., of University College; by Mr. W. P. Pycraft, of the Natural History Museum; and by Mr. Athol Joyce, of the British Museum. He has also to acknowledge gratefully the permission given to him to reproduce photographs and diagrams by Dr. R. S. Lull, of Yale University, who sent him a photograph of his Restoration of Primitive Man; by Professor John Milne, F.R.S., of Shide; by Professor W. H. Pickering, of Harvard; and by Dr. Tempest Anderson.

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THE BIRTH OF SOLAR SYSTEMS

Mutual attraction of heavenly bodies near to one another—Nebulæ and their classifications—Laplace's nebular hypothesis—Evolution of elements—Objections to Laplace's hypothesis—Spiral nebulæ—Roche's limit—Approach of solar systems—The formation of a spiral—Chamberlin and Moulton's hypothesis—Modifications of Laplace's theory—Star drifts.

AMONG the common facts of daily observation there is none of greater usefulness in illustrating the causes which precede the birth of worlds, than the occurrence of the tides. The tides afford a ceaseless illustration of the operation of that mutual attraction which all bodies have for one another, which is called the law of gravity. The waters are gathered up before our eyes in response to the attraction exerted on them by the nearest of the Earth's neighbours, the Moon, or by the greatest, the Sun. They recede again in obedience to the operation of the coupled influence of the Earth's attraction and of their own inertia. For the moment, the effect of the law of inertia, by which every body perseveres in its state of rest or motion, may be disregarded in order that the attention may be concentrated on the picture of the Earth's mobile waters lifted up from their sphere towards the heavenly body which attracts them. If the Earth could be thought of as a body wholly fluid, then the picture would become that of a spherical mass converted into one that was egg-shaped, with the longest axis of the egg pointing towards the source of attraction.

Nebulæ and their Classification

Before applying these considerations to the approach of stars to one another, it becomes necessary to scan the heavens to see what information they have to afford about the formation of worlds in progress. It is not possible within the limits of human observation ever to have seen any starry phenomenon which can be positively identified as a stage in the formation of a solar system. But among the hundred million bright objects visible in the universe, it is probable that all the preliminary stages are represented, and it is possible that in some of the phenomena which have periodically been witnessed among them, the actual birth of a new solar system, eventually to be resolved into a sun and planets, may have been included. In the sky are 500,000 visible nebulæ. These bright apparitions, in many cases of indefinably great extent, are regarded, in default of any better hypothesis, as the raw material of worlds.

They are of two kinds. When the light from some luminous object—a red-hot poker, a candle flame, burning magnesium, the sun, a star, a nebula—is passed through a prism, the light is split up and spread out lengthways. If the source of light is an incandescent solid, like the sun, the light coming through the prism is spread out in a *continuous* rainbow band. It forms a *continuous spectrum*. If, however, the source of light is merely a bright gas, then the rainbow band on the screen is amplified by another apparition. It is that of a number of bright lines, which by the places they occupy afford certain information as to the nature and constituents of the gas. This bright line spectrum is called a discontinuous one. Many of the nebulæ of the sky, and some of the greatest ones, yield to observation nothing but these bright line spectra. The positions of their bright lines mean apparently that the glowing gases which compose them are hydrogen, helium, and an element unknown on earth, and

called, for an evident reason, nebulium. These nebulæ are vast but formless; and, except for the two elements we have named, appear to have little in common with the elements of our solar system. Are these the unfertilized germs of systems yet unborn? It is characteristic of the decay of theories as knowledge advances, that a less decided answer can be given to that question than would have unhesitatingly been put forward a generation, or half a century ago. The vast formless nebula had a distinct place in the theory known to everyone as Laplace's Nebular Hypothesis.

Laplace traced the origin of the solar system to a nebula or cloud of rarefied gas congregated round a central condensation which was ultimately to form the Sun. The preliminary difficulty that the gaseous constituents of such primal nebulæ as are known to our observation are very much fewer in number than the recognized constituents of the solar system, may be surmounted by postulating a process of evolution among the elements themselves. The elements have been grouped by chemists in certain orders like the rungs of a ladder. Thus a group of elements may have the same general qualities, a certain family likeness: and may differ from one another primarily in their atomic weight. Thus from hydrogen we have the descending group, chlorine, bromine, iodine. The oxygen series is grouped—Oxygen (atomic weight 16), chromium (atomic weight 52), below that molybdenum (atomic weight 96), with tungsten (atomic weight 184), and uranium (atomic weight 238) lower down the scale. It has been supposed that we may imagine a certain cycle of circumstances in which one kind of element is formed; and that as evolution goes on and circumstances become altered, another kind of element becomes possible and eventually survives and becomes stable. Thus though in some nebulæ we are now able to perceive only hydrogen, helium, and nebulium, it is possible that in these constituents lie the potentialities of other elements.

The atoms of which matter is composed are continually radiating energy and so losing it; and therefore a time must come when the atoms of an element must run down as a clock would. When this time comes the atom of one element will perhaps transmute itself into the atom of another element which needs less energy than is required in the first state. Sir J. J. Thomson has said that an atom constructed on the theoretic model might be made to run for a million years, but it would not be eternal. There is good reason to believe that in radium and in other elements possessing very complex atoms we do actually observe that break-up and spontaneous re-arrangement which constitutes a transmutation of the elements. Therefore it is not a sufficient objection to Laplace's theory that the nebulæ of the sky do not exhibit many of the elements known to exist in the solar system.

To return, however, to Laplace's hypothetical nebula. The whole was slowly rotating about an axis through its centre, and under the combined influences of rotation and of the mutual attraction of the particles of the gas, it assumed a globular form slightly flattened at the poles. The nebula must have gradually cooled by radiation of its heat into space, and as it did so the gas must necessarily have lost some of its spring or elasticity, thus permitting a greater degree of condensation. But as this contraction took place two results followed. First the central condensation became hotter; and, secondly, the speed of rotation became faster. The quickened rotation led to an increase in the amount of polar flattening, and in the course of millions of years the nebula, growing flatter and flatter, assumed the form of a double convex lens or that of a disc thicker in the middle than at the edges.

Difficulties multiply, however, if pursuing the career of a rotating gaseous nebula an attempt is made to reconcile it with the forms and motions of a solar system. Laplace

went on to suppose that the nebula became so much flattened that it could not subsist as a "plate" of gas and that a ring of matter detached itself from the mass and revolved about it. Possibly the rings of the planet Saturn suggested the idea to Laplace, who further argued that the parent mass, with part of its unmanageable flatness thus removed, would resume the more rounded form which originally it possessed. The first process would, however, be repeated in course of time, and another equatorial ring would be shed. In this way the primal nebula would be split up into a number of rings surrounding the central condensation. Each ring gradually closed in on some nucleus which happened to exist in its perimeter and thus formed a subordinate nebula revolving about the much-reduced and concentrated parent nebula. The parent nebula gradually cooled to incandescence. The offspring nebulæ did likewise, creating for themselves by a repetition of the ring process, attendant satellites. The whole process, as Sir G. H. Darwin remarks,[1] forms a majestic picture of the history of the solar system. Plausible in conception, it fails however when examined in detail; as a single instance may serve to show. For example, if a ring of rotating matter ever concentrates at all under the influence of the mutual attraction of its particles, it can only do so round the centre of gravity of the whole ring. Evidently if the ring is approximately uniform this centre must be somewhere in the neighbourhood of the parent nebula. Consequently the only future of an attendant concentrating ring nebula would seem to be that of falling in again as to the primal nebula, and of being re-absorbed.[2]

Without pursuing these criticisms of detail further, we may perhaps say that the action of some external force,

[1] Presidential Address to the British Association in South Africa, 1905.

[2] Further mathematical objections to the theory have been recently raised by Mr. F. R. Moulton, "Astrophysical Journal," March, 1900; and by Mr. J. N. Stockwell, "Astrophysical Journal," March, 1904.

other than that of the mutual attraction of the particles of the nebula, has to be imagined in order to explain the origin of its developmental formation into a system. The origin of the nebulous mass from which the solar system was supposed to have been evolved was not considered by Laplace. He assumed its existence, and its rotation; and then proceeded to show, as he thought, how the sun and planets might have been formed from it in the course of ages. Laplace, however, lacked one piece of knowledge which modern astronomers and the constructors of modern cosmogonies possess. He was ignorant of the ubiquity of spiral nebulæ. The discovery of spiral nebulæ was originally made by Lord Rosse; and though the existence of these formations was doubted at first, photography has so fully confirmed it that of the hundreds of thousands of nebulæ[1] which have been disclosed by the Crossley reflector, at the Lick observatory, the greater proportion assume this form. Prof. J. E. Keeler remarked that "any small compact nebula not showing evidence of spiral structure appears to be exceptional". Herr J. Wilczynski of Berlin has shown mathematically that a spiral form would be assumed by a rotary gaseous mass.

The spiral nebula is then an existing reality. It probably represents a step forward in the evolution of a starry system, or a solar system; and the reasons for thinking this are not merely that it represents the emergence of a definite form, but that the spiral nebulæ are shown by the spectrum to have a constitution different from those nebulæ which are hypothetically formless masses of electrified gas. The spectrum they yield under observation is continuous. From that we infer that the matter of which they are composed

[1] "The Crossley Reflector," by J. E. Keeler "The Astrophysical Journal, XI, 325" (1900). Keeler found 120,000 nebulæ before his death in 1900. Prof. Perrine has since suggested 500,000 as the approximate number.

exists at a relatively low temperature and in a liquid or solid condition. The fact that such nebulæ are enormously spread out, that they apparently intercept but little light, and that they seem to have but little attractive power, suggests that this solid matter exists in a finely divided condition.

The Near Approach of Heavenly Bodies

Before stating a hypothesis which seeks to explain the shape of these spiral nebulæ and which extorts from it an explanation of the way in which a solar system arises therefrom, we may return to the consideration with which this chapter began, of the effects of the mutual attractions of neighbouring or approaching bodies. Imagine a small liquid sphere, the particles of which cohere only by their own mutual attraction, or gravitation—to be moving through space and to pass near a large dense body. (For the purposes of illustration we will suppose that there is a very large difference in the density and mass of the two spheres.) As the light small sphere comes within a certain distance of the great one its particles will become subjected to the strong attraction of its neighbour. But the particles nearest to the heavy neighbour will be attracted more strongly than those further away, because gravitative attraction is a force which varies in intensity as the square of the distance. Thus what is called a differential attraction of the small sphere's particles will be set up: and this differential attraction will in certain circumstances be powerful enough to tear the small unstable sphere into fragments. The distance at which this disruptive force comes into action was defined by the French mathematician Edward Roche of Montpellier and is called Roche's Limit. Roche announced in 1848 that within a limit of about two and a half times the distance of a planet's radius a stable satellite could not exist. Thus no satellite could exist within 10,000 miles of the earth.

The law is accepted as true for the close approach of

any two bodies of sufficient mass and density. It seems likely that mutual gravitation as thus pictured would more effectively disrupt relatively large bodies than smaller ones; for example, it would be more likely to break up a body of the size of the Earth or of the Moon than one of the small asteroids which are travelling in the solar system. The outer portion of our earth (and doubtless that of the satellites of planets; of asteroids; and of cold planets generally) is deeply traversed by fissures which render it little more than a pavement of dissevered blocks, such as could be lifted away with but little resistance beyond that of gravity. In other words, if an attractive force, slightly stronger than their own weight, were applied to the tesselated mosaic of a planet's crust, fragments of it would yield to the attraction.[1] What would then happen? The relief of pressure below a planet's crust, caused by the lifting of great fragments of it; and the sudden exposure of the hot interior to a lower temperature would develop new stresses and strains. There would be further splitting up and fissuring of the crust; and there would in consequence be further removals. There might be sufficiently great disruption from this cause alone to break up the solid shell into fragments or even to reduce the fragments to dust. Were the Earth to be subjected to an experience such as has been described it is likely that the interior gravitative stresses having been suddenly removed, its internal elasticity would blow its exterior to pieces with all the violence of an explosion.

According to the mathematical consequences of Roche's Limit, the distance at which the disruption of one planet approaching a larger one would set in, would be from five to seven and a half times the radius of the larger body. We

[1] For a fuller exposition of this and the following theories reference should be made to a paper by T. C. Chamberlain in the "Astrophysical Journal," July, 1901.

thus see that solid bodies might be split into fragments without coming actually into collision with other bodies. What would happen to small planets thus broken up? They might constitute comets, so long as the fragments remained clustered together; and thereafter, should the fragments become dispersed, they might constitute trains of meteorites. But an explosion of the kind we have imagined would not carry a very great distance. The matter of an exploded earth, or of a similarly aged planet, after flying out to a distance of perhaps 600,000 miles, would again be assembled into a planetary body by its strong self-gravity. Such a hypothetical occurrence has suggested to Professor Chamberlin the explanation that temporary new stars, which soon sink again into invisibility, may be the outcome of explosions and subsidences of this kind.

If, however, larger bodies, or larger systems of bodies, are to be considered, we must frame other hypotheses. What would happen if two stars came near one another or if two solar systems approached within effective distance?

Two solar systems might perhaps approach sufficiently close to influence the outer planets of either system. One system might capture the outermost planet of the other. If, however, our own system's Neptune (or the planet which Professors Pickering and Forbes have postulated beyond Neptune) were to disappear the orbits of the interior planets would be disturbed. Even if the approach were less intimate than this, and only tended at first to elongate the orbit of the outermost planet by drawing it further from the sun, yet there would be a disturbance of the orbits of Uranus, Saturn, Jupiter and all the other neighbours of the domestic circle. But if the approach of the solar systems left nothing greater than 500,000,000 miles between their centres, the disturbance of the planetary orbits would be of a more pronounced kind. It might, and probably would, lead sooner or later, to the fall of some disturbed planet on to one of the

interior suns. Then would follow an overwhelming outburst of heat. It is possible that the astronomers' telescopes have witnessed some such occurrence in cases where a dimly bright star has blazed into a sudden higher luminosity, and the brightness has appeared to travel outwards on either side of the central glow.

THE BREAK UP OF A SUN

There remains the last case to be considered: the disruption of a sun. We have spoken of the internal elasticity of a body—that force which seeks to burst outwards from the centre of a sun, and of which the evidence is to be seen in the great streamers of incandescent gas on the sun's rim. It is balanced by the self-gravitation of the sun's particles, which draws them back towards its centre. But if by any means this balancing force is disturbed, for example, by the attraction of some approaching body then this internal elasticity may aid in the disruption of a sun before the approaching body comes within the limiting distance prescribed by Roche. Thus (to return to our first picture of the waters of the Earth being drawn up towards the attractive Moon) when a gaseous body or a gaseous-liquid, or gaseous-liquid-solid body like the Sun, begins to approach the sphere of attraction of another great body, a kind of tidal elongation sets in. The gaseous liquid envelope is drawn out along a line joining the centres of the two bodies. For simplicity we will first consider the instance when a gaseous sun A comes into the sphere of attraction of a great solid body B. When they approach near enough the self-gravitation of A's particles will be neutralized along a line joining the centres of A and B: and like a tide the gaseous liquid envelope of A begins to stretch out towards B.

As the two approach one another the elongation is going on at a rate which, if an observer were there to witness it, would appear to give it the appearance of an explosion. The

rate of elongation would in fact be very nearly as great as the rate of an explosion.

Something more than this would happen. The imaginary observer would see these two great flaming arms shoot out from the molten mass of their parent, but as the suns approached one another the flaming arms would begin to curl. That would be because their sun was beginning to rotate. The streamers from a Catharine wheel firework, as it spins, will give an idea of how this happens.

Let us sum up the stages of the history of this typical sun A as it approaches B.

There is firstly a rapid elongation of its shape.

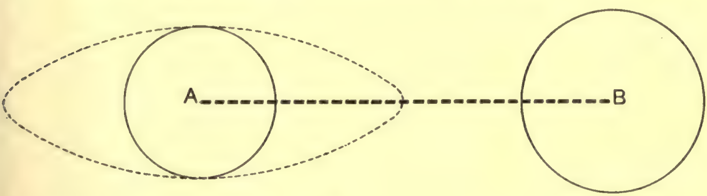


FIG. 1.

There is secondly an elongation so rapid as to be almost explosive.

This elongation continues and is combined with another motion, which is that of rotation towards the solid great body.

This secondary motion will be apprehended from a diagram of the intersecting paths of the two bodies (see p. 12). It will be seen that owing to the alterations in the direction of the line of attraction between A and B in their successive positions A_1 A_2 A_3 A_4 and B_1 B_2 B_3 B_4, that a spin will be imparted to A. It will rotate towards B. The explosive shooting out of great arms of matter from A combined with the rotation which is imparted to A at the same time will give rise to a spiral form.

There would be a certain brief period when the ex-

plosive projection of the sun's matter would reach a climax. A stream of material rushing out in much greater volume and at a much greater velocity than before or afterwards would be shot out in two great protuberant arms of matter on either side of the sun and there should be then, to sum up, two chief arms to the resulting spiral, starting from opposite points of the central mass and extending outwards to the limits of the spiral. These must be travelling in a common direction owing to the rotation of the mass.

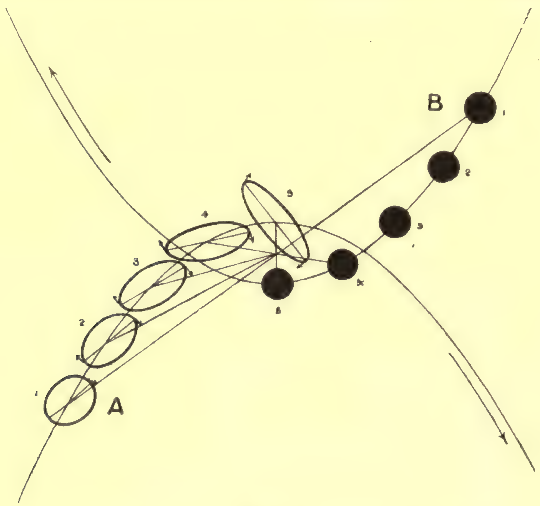


Fig. 2.

For ease of illustration we have supposed this action to have taken place when a visiting heavy dark body passed near a sun. But the theory with necessary modifications is equally applicable to an instance where two suns similarly visited one another. This is possibly a more actual, or a more typical instance. In the result there might be mutual dispersion without serious collision. Without cataclysmic contacts the two resulting spirals would separate and would pursue the paths marked out by their parent stars.

It is not hard to see, as our ancestral sun with its visiting sun swung about one another in their transient approach, that secondary arms would be formed; that the outbreak would be irregular and pulsatory, with the formation of condensations in the arms; and that there would be a scattering of a large amount of ejected matter in the form of a surrounding haze. Owing to the play and interplay of the generating forces, the lumps in the arms would themselves have rotation and movement. They would be vortices and they would have their subordinate vortices. Finally, this widely distributed matter would sooner or later fall gravitatively into the centres of its vortices and would congeal into solid lumps and particles; and a spiral nebula with such constituents would yield to observation a continuous spectrum.

This extremely suggestive and reasonable hypothesis, framed by Chamberlin and Moulton, can be applied to explain most of the great spiral nebulæ which have yielded evidence of their forms to celestial photography. In some cases an extension of the possibilities of collisions is called for. For example, the shape of some nebulæ seem to demand the hypothesis that there was a partial collision between two stars. The heat arising from the impact, or from what in mechanics is called "arrested momentum," taken together with the mutual attraction of the two stars, would impart a rotary movement of the highest order to the two systems. In some instances the consequences might be the fusion of the two stars into one giant nebula. Or if there were a partial arrest of the forward motion of one or other then certain parts of either star might escape from the main spiral. Such a catastrophe is possibly visible in the nebula in Canes Venatici. There are other instances, and other departures from the regular type, the mechanics of which the theory endeavours to explain; but at present the cosmogony thus framed is applicable as an explanation to

the spiral nebulæ as a whole, and is one of the most useful as affording a plausible explanation of the circumstances which gave birth to the system of planets surrounding the Sun.

. . . .

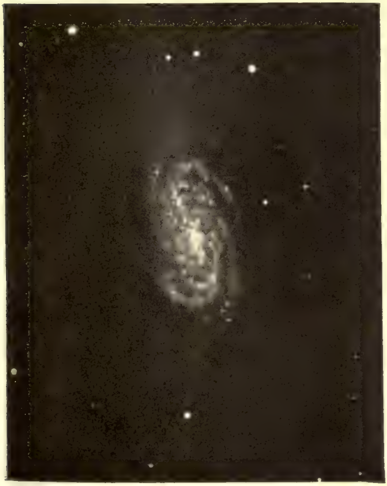
Such is the theory which, if the likelihood of the near approach of two suns be granted, furnishes a plausible explanation of a birth of a system such as we know that of the Sun and its planets to be. It is, however, necessary to add that since the theory is hardly older than the twentieth century itself, it has not been subjected to the searching kind of criticism which for more than a century has been directed at Laplace's Nebular Hypothesis.[1] Nor must it be forgotten that attempts have been made to improve Laplace's theory so as to construct a cosmogony which should be more adaptable to observed facts. For example, two principal modifications of Laplace's scheme have been proposed : (1) the substitution of a thin plane spiral for his nebulous sphere ; (2) the introduction of tidal action to explain many of the details. If we substitute a thin plane spiral for the nebulous sphere we shall at any rate have the support of observation, for many such spirals exist in the heavens ; and we need not assume such an extreme tenuity for our primeval nebula as Laplace had to do. Sir Robert Ball's variant of this spiral hypothesis,[2] sets out by laying down the proposition that a sphere of moving particles has a tendency to spread itself out as a disk. He deduces this from the fact that in any system of moving forces, the sum total of the results of the interactions of the forces (or what is called the "moment of momentum") will always remain the same ; but that the "energy" of the system diminishes with each collision of its particles. The

[1] Laplace announced his hypothesis in 1786 as a note to his "Système du Minde". Mr. W. W. Bryant ("A History of Astronomy," p. 60) says that Laplace inclined to regard the theory as very speculative.

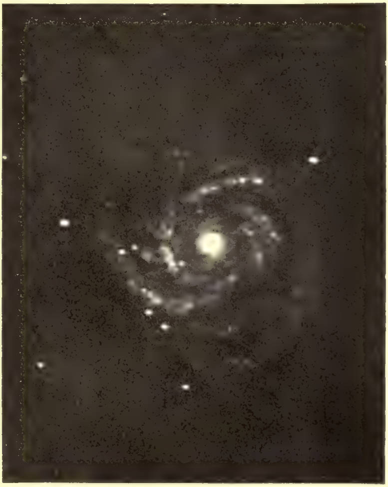
[2] "The Earth's Beginnings," pp. 243-7.

H.V. 44 CAMELOPARDI

M. 81 URSAE MAJORIS



H.I. 56-57 LEONIS



M. 100 COMAE BERENICES

TYPES OF SPIRAL NEBULÆ

From Nebulæ and Clusters made with the Crossley Reflector by J. E. Keiller
(Publications of Lick Observatory. Vol VIII. 1908)

particles after collision would drift towards the centre, and the system tends to that form which combines a minimum of energy with the preservation of its original momentum (or shall we say "life force"?). This form can be shown to be a flat disk widely stretched out. The drift of particles towards the disk's central portion would cause this part to rotate more rapidly than the outer part. Spiral structure would be the result of these differentiated movements. By some process, of which we cannot trace the details, knots or nuclei appeared on the whorls of the spirals, and these formed the embryos of the planets.

Star Drift and Star Collisions

The weak point in Moulton's cosmogony of spiral formations is that a large number of celestial collisions or interferences have to be assumed. The number of such impacts or approaches must amount to some hundreds of thousands, if we are to take the spiral formations as evidence of them. That is perhaps not a very large number out of the 50,000,000 stars which are visible on the photographic plates of the Star Catalogue of the twentieth century; and the proportion of the numbers of the spiral nebulæ to those of all the bodies in the universe dwindles still further if the assumption is made that the majority of bright stars are accompanied by dark spheres or satellites which cannot be seen. Even so, however, the number of collisions seems large. In regarding the solar system we think of the orbits of its planets as having assumed a condition of stability in which they are not likely to interfere with one another. The orbits of the starry systems of the stellar universe would seem to be less stably fixed if we are to believe that even one in ten thousand of its units shows evidence of having wandered into the sphere of attraction of some other unit.

We cannot, on the other hand, assume that the visible universe is a system which has arrived at or is approaching

equilibrium. We know nothing of its mechanics; nothing of its limits; and next to nothing of its plan. There are grounds for believing, however, that it is not a single universe at all, but that it is multiple; that there is not one system of stars but at least two. This surmise was first stated by Prof. J. C. Kapteyn of Gröningen, at the St. Louis Conference of Arts and Sciences in 1904;[1] it has been subsequently confirmed by Mr. A. S. Eddington, of the Royal Observatory, Greenwich,[2] and by Mr. H. C. Plummer, of Oxford University. Their conclusions were arrived at by an examination of the Star Catalogue made by Bradley and Groombridge[3] and by noting the movements of the stars since the dates at which these catalogues were compiled. For a most illuminating illustration of the way in which these conclusions were reached we are indebted to an article by Prof. H. H. Turner in the "Fortnightly Review" of April, 1907.

Consider, he says, the common case of a man who is walking along a road in the hope of being overtaken by an omnibus. He always meets a number of the desired omnibuses which is irritatingly large in comparison to the number which catch him up. That is not surprising, because if the omnibuses are travelling at an average of six miles an hour, and he is walking four miles an hour, then he ought to meet five omnibuses for every one that passes him. (The ratio is mathematically obtainable by adding the two paces in one case; subtracting them in the other; and taking the proportion. Thus $6 + 4 = 10$; $6 - 4 = 2$; $\therefore$ ratio $10 : 2$ or $5 : 1$.) If the walker drops his pace to a saunter of two miles an hour, the ratio will fall to two 'buses met for every one that passes; while if he begins to accelerate his pace towards six miles an hour the ratio becomes enormous.

[1] "Congress of Arts and Seiences, St. Louis," 1904, Vol. IV, p. 419.

[2] A. S. Eddington, "Royal Ast. Society, Monthly notices," Vol. LXVII, p. 34. Houghton Mifflin, 1906.) H. C. Plummer ("Royal Ast. Society Monthly notices," Vol. LXV, pp. 566-9.)

[3] Bradley (Kapteyn), 1750; Groombridge (Eddington), 1810.

So that if ultimately he walks actually as fast as the omnibuses are travelling he will never be caught up at all; and if he walks faster still he will presently begin to overtake omnibuses. These will, in effect, slowly come back to him from the same direction as those which he is actually meeting. There may be, however, other more swiftly moving vehicles like trams or motors which will still overtake him from behind. If they form part of a regular service the same rules will apply to them.

In short, whatever miscellaneous traffic there be on the road, providing it is moving backwards and forwards equally, the man can calculate the ratio of vehicles which will meet him to those catching him up, if he knows his own pace and the pace of the vehicles.

But in order that this state of things should be of use for calculating purposes, it is evident that the vehicles must not all be coming in one direction; they must be moving backwards and forwards equally. As long as they are doing that, the walker can find out something else beyond relative speeds. Suppose him for a moment to be suspended in a balloon above the highway, at night, and suppose that all the vehicles carried lights. In a balloon the sense of motion is so imperceptible that it is impossible to tell the direction of movement except from other objects. In the balloon above the travelled highway it would be quite simple to find in which way the balloon was travelling. Evidently it would be moving towards that direction from which *most* lighted vehicles appeared to come, and away from that direction which sent least.

Furthermore, if the balloon were suspended over a great plain over which vehicles were travelling in a broad stream, the aeronaut could count the number of lights coming from different parts of the compass towards him; and having ascertained from which quarter most appeared to come would know the balloon was travelling thither, or having

identified the quarter which sent fewest would know he was travelling thence. On the plain over which the airship hovers it does not matter whether all the vehicles are travelling backwards and forwards in the same direction (as for example north and south). The vehicles coming from north-west or north-east will apparently increase the number, due to the fact that the balloon is partly sidling in either of these directions, but the increase will not be as great as the direct increase from the north; east and west will not be affected at all; and the decrease from south-east and south-west will not be as great as the decrease from the south. As the balloon goes round the compass there will always be one maximum and one minimum; and the balloon's direction can be inferred as towards the maximum or from the minimum.

But suppose the second method of calculation does not give the same result as the first. Suppose the direction from which most lights come is not exactly opposite to that from which fewest lights are sent. Each ought to give the balloon's line of flight. Each ought to be the same in direction. But the balloon cannot be moving in two directions at once: there must be something wrong.

The thing that is wrong is the assumption that the traffic below the balloon is travelling indifferently in both directions, or backwards and forwards in all directions. Unless that is happening our rule will not apply. Conversely, if if our rule will not apply the thing is not happening. In other words, the traffic of the lighted vehicles, the stars, of the universe cannot be considered as a uniform whole.

It is not one great star drift. It is a composite movement made up of portions which have different systematic movements.

It was in this way that Prof. Kapteyn inferred the existence of two sets of stars, or a double universe. His actual words were:—

We thus in reality have determined the apex of the solar motion, separately, from the stars having direct motion from those having retrograde motion. Instead of finding the same point or opposite points we find *two* points lying 125 degrees apart.

We will conclude there are two sets of stars. The motion of the sun relative to the one differs from that relative to the other set.

It follows that one set of the stars must have a movement relative to the other set.

Prof. Kapteyn gave a first approximation of the relative medium of the two streams or drifts of stars. The line of approach to one another is that joining our Sun to the star ξ in Orion, and lies almost exactly in the plane of the Milky Way.

Mr. A. S. Eddington has corroborated and amplified Prof. Kapteyn's results, working them out himself by comparison with the Groombridge catalogue of stars. Now we have said that the aeronaut travelling north will meet most lights coming from the north; and the fewest from the south. Let him represent the number counted from any direction by a line drawn from a point O in that direction, and just as long in centimetres as the number he counts. Thus :—

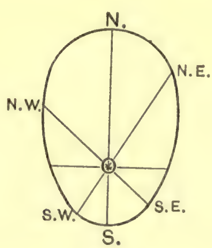


FIG. 3.

If there were but one star drift, the observers would get an oval something like the figure above. But when Mr. Eddington drew his curve he found it not an oval at all: but resembling something which Prof. Turner has compared

to a rabbit. The curve had a distinct neck at one end which disqualified it as an oval, and from a mathematical point of view helped Kapteyn's hypothesis that there were two drifts of stars. Mr. Eddington showed that the rabbit curve might mathematically be considered as a complete curve consisting of two ovals. He analysed it and then synthesized it; and demonstrated that to each oval might be assigned certain stars. He did this six times with different groups of stars; and he showed that the curves indicated satisfactorily the same pair of universes or "star drifts". One star drift travels at the rate of seventeen miles a second; the other at five miles a second. The drifts must intersect; and Mr. Eddington notes that the special abundance of stars in the Milky Way is due equally to both drifts.

If there are then two or more drifts of stars, the possibility that the double or multiple universe has not reached a stage of stability in which collisions are improbable, becomes greater. But it would be indefensible to assume that collisions are probable; and the most we can say of the collision hypothesis is that it serves its purpose very well till we know more about the causes which produce atomic disintegration.

A corollary to the idea of the existence of a twin universe of stars, is that which has of late taken shape under the name of Migrating Stars,[1] a name given to clusters of stars which, apparently moved by some common impulse, seem to be moving in the same direction. In a paper published in 1908, Prof. Lewis Boss,[2] of Albany, already well known for his long-continued work on the positions and movements of fundamental stars, announced that no fewer than thirty-nine stars, scattered over an area as large as the Great Bear

[1] "Migrating Stars," by Prof. H. H. Turner ("Fortnightly Review").

[2] "Convergent of a Moving Cluster in Taurus," by Prof. Lewis Boss ("Astrophysical Journal," 604 (1908), September).

in the sky, were all moving accurately towards the same point. It is not suggested that they will ever meet; on the contrary, the evidence seems to show that they are moving in parallel lines; but by the laws of perspective these lines appear to converge to a vanishing point, which Prof. Boss named a convergent. A similar idea was first mooted by Proctor[1] forty years ago. He showed that large groups of stars were animated by a motion across the sky in the same direction and at the same rate. The most striking instance arises in the seven stars of the constellation of the Great Bear or Plough. The middle five of the seven are speeding in company away from the earth: the two "pointers" at the end of the Plough are coming towards us. But these two are not alone in the heavens. They belong to the same company as Sirius; to which company also belong six other stars—the brightest star in the Northern Crown, one in the Lion, one in Eridanus, one in Auriga. These have been discovered by Dr. Ejmas Hertsprung,[2] of Göttingen. They are scattered widely over the sky, and there may be others still undetected. They move in parallel courses through the universe of stars like a flock of migrating birds, and some of their brilliant squadron have passed us by and some have not yet caught us up. It is possible that our sun is one of a cluster of stars moving like this. The variable star Algol with its dark companion may be moving with us; and so may be its neighbour the Beta of the constellation Perseus; and one star of the Eagle, and two of the Swan may be going our way. Prof. Boss' disclosure of the parallel movements of thirty-nine stars has given a new impetus to the study of these flocks of stars, whose movements and the possibilities of whose movements are more mysterious than those of any birds. Can it be, asks Prof. Turner, that such star flocks have some common association

[1] "Proc. Roy. Soc." Vol. XVIII, p. 169.
[2] "Astrophysical Journal," XXX, p. 138.

of birth, perhaps some vast nebula which collected into stars, billions of years ago, as a cloud condenses into drops, and which yet retains in them its vast extension and its primeval velocity?

Types of Stars

Whatever theory we may adopt for the earlier stages of evolution in the solar systen, we come to a time when such a system had developed into a number of large orbs of a high temperature. The life history of each may have differed. It is presumed that none for example was ever in a sun-like state; the larger planets were nearer to such a state, the smaller ones further from it; and the smaller ones would cool more rapidly. The Sun alone among them bears affinity to the stars. It is presumed to have passed through the varying stages which the spectroscope has disclosed among the units of the stellar universe.

Stars have been divided into a number of types varying with what we know of their constitution. The first type consists of bluish-white stars, of which Sirius, the brightest of them all, is the most conspicuous. Such stars are simpler in constitution than the Sun, and their atmospheres are very thin and rich in nothing recognizable except hydrogen. Analogous to these are the stars of the helium type, which show strongly the presence of this gas. Helium has long been known to exist in the surroundings of the Sun; it has more lately been found on the Earth; and it has been specially identified with the emanation of radium. When helium is dissociated from radium its birth is accompanied by an extraordinary display of energy. Prof. Simon Newcomb suggested that the presence of helium in the stars might be a symptom of the existence of some immense stores of energy,[1] then unknown to us in which was to be sought the origin of their evolution and development

[1] "The Star: A Study of the Universe."

The disclosure of the properties of radium has illuminated this utterance. The breakdown of the radium atom is accompanied by the release of relatively enormous stores of energy. It is possible that the origin of stellar systems should also be sought in the release of atomic energies in the starry crucibles.

Stars of a second type have a golden tinge and to these our Sun belongs. The golden hue is akin to a fog veil, or to an obstructing layer in the sun's atmosphere which absorbs much of the violet light. The third type includes the Red Stars, which when examined by the spectroscope reveal many metallic lines, those of calcium, iron, sodium, and magnesium among them. In 1904 Prof. Fowler found another metal in many of these stars—titanium. Such stars are often variable and it is probable that they are nearing the end of their career as suns. Another type of Red Stars, found chiefly in the neighbourhood of the Milky Way, shows the presence of carbon and cyanogen. They, too, seem to be approaching extinction but this decadence is different in kind from that of the others. The remaining types of stars are youthful. They are believed to be still very largely gaseous. Some show hydrogen and helium strongly; others, which are chiefly found in the Milky Way, like the faint red stars, may possess hydrogen, but if so, the gas exists in some condition unascertained on Earth. In one of these stars has been found a trace, perhaps we should say a symptom, of oxygen, a gas very rarely found in any stars, and only just traceable in the Sun; but none has any trace of metals.

Probably the Sun was at first a helium star with nebulous wisps stretching about it. It would cool thence to the Sirian stage, very bright, and with no veiling layer of atmosphere. This kind of star is much commoner than the helium star; so presumably the later stage endured longer than the first. By slow degrees the Sun would pass to its present golden

yellow condition, as the solar atmospheric layer cut off more and more violet light ; and perhaps in the future it will grow redder and redder. In its old age its light, in which some traces of variability have already been found,[1] will become markedly variable and there will be great outbursts of glowing gas.

[1] "Solar Radiation," by C. G. Abbot (Publications of the Smithsonian Institute), 1908.

CHAPTER II

THE BIRTH OF SATELLITES

Planetary orbits—Shapes of planets—Momentum of planet and satellite —Tidal friction—Earth and Moon—Separation of Moon from the Earth and comparison with it.

LET us now, however, leave the consideration of the temperature of the glowing orbs which were satellites of the Sun when it was still a helium star; and consider the manner of their growth. An illuminating illustration was furnished by Sir G. H. Darwin in his Presidential Address to the British Association at Johannesburg.[8] Imagine, he said, a sun round which there moves in a circle a single large planet which we will call Jove. Suppose next that a meteoric stone or small planet is projected in any perfectly arbitrary manner in the same plane in which Jove is moving. How will this third body move? Under the combined attractions of the Sun and Jove, the meteor will travel in a path of extraordinary complexity. At one time when at a great distance from both the Sun and Jove it will move slowly; at other times it will race like a comet close past one or other of them. As it grazes past Jove or the Sun it may often only just escape a catastrophe; but a time will come at last when it runs its chances too fine and comes into actual collision. The career of the meteor is then ended by absorption; and, of course, by far the greatest chance is that it will find its Nirvana by absorption in the Sun.

[1] South Africa, 1905.

Now if instead of one meteoric stone or minor planet there are hundreds of them, moving at the beginning in all conceivable directions, then since they are all so small as not to influence one another, they will all move almost as if they were influenced only by the Sun and Jove. Eventually, most of them will find their way into the Sun; a smaller number will add themselves to Jove. If we proceed to ask how long the individual career of a stone will endure, there we shall find that mathematically it depends how fast, and in what direction, it was travelling at the beginning. If we give it speed enough and start it in the right direction, it will elude both the Sun and Jove and never come into collision with either. We put this fact in another way by saying that there are certain perpetual orbits in which a meteoric stone or a minor planet may move for ever without collision.

But when such an immortal career has been furnished for our minor planet, it still remains to discover whether the slightest possible departure from its orbit will shorten its life. Will such a departure become gradually greater and greater, and so cause the minor planet to come ultimately into collision with one of the two great magnets; or will the minor planet travel so as to return to its perpetual orbit, crossing it and recrossing it, but always remaining close to it? If the slightest departure from the narrow road inevitably increases as time goes on, we call the orbit unstable; if, on the other hand, departure only leads to a slight waviness in the path described, the orbit is stable. Thus we arrive at another distinction. There are perpetual orbits, but some, indeed most, are unstable and these do not offer an immortal career for a meteoric stone. There are other perpetual orbits which are stable or persistent. The unstable ones, in Sir G. H. Darwin's phrase, are those which succumb in the struggle for life. The stable ones are the species adapted to their environment.

Finally: if then we are given a system of a sun and a large planet, together with a swarm of small bodies moving in all sorts of ways, the sun and planet will grow by accretion, gradually sweeping up the dust and rubbish of the system, and there will survive a number of small planets and satellites moving in certain definite paths. In the end we shall have an orderly planetary system in which the various orbits are arranged according to some definite, if unknown law. If we could treat our solar system as an exact mathematical theorem in which all the quantities were known, Sir G. H. Darwin believes we should find that the orbits of the existing planets and their satellites were numbered among the stable perpetual orbits.

Shapes of Planets

This process, by which a planet adds to its size by absorbing its less powerful and steady neighbours, would begin before, and while, it was in the liquid state. We have now to consider, however, a form of stability independent of the planet's orbit, the stability of its shape. Nearly everybody knows that a rotating fluid mass is shaped rather like an orange, bulging slightly at its middle, flattened a little at its poles. Its shape is due to two quite evident causes. The equal attractions of gravity tend to make its particles group themselves in a regular sphere. Centrifugal forces coming into play tend to make the particles fly off into space. But a particle on the globe's equator is travelling very much faster than one in the Arctic circle (where, as the particle is nearing the pole, so its rotatory speed is approaching the vanishing point). Therefore at the equator the centrifugal force outwards tends to counteract to a greater extent the pull of gravity inwards. To put the matter in another way, a particle at the equator virtually weighs less than at the pole, and is squeezed out further by the particles which weigh more. Thus a spinning sphere has a longer

diameter across the circle of its equator than from pole to pole.

A spinning sphere, therefore, becomes a spheroid; and the faster it spins the flatter it grows. The planets afford us an illustration of this, for Jupiter is flatter than Mars: a result presumably due to a disparity in their speed of rotation at an early stage in their life history. But a planet cannot go on increasing its speed of rotation, and flattening itself in the process indefinitely; for if that were the case all planets would have become disks. At some point its growing instability reaches the breaking point. Something else happens. Equilibrium breaks down when rotation attains a certain critical velocity, varying according to circumstances, and the spheroid either alters fundamentally in shape, or goes to pieces.

Yet what actually happens can only be partially determined; and this great problem in celestial mathematics is one which advances to a complete solution very slowly. M. Poincaré first grappled with it in 1885. Sir G. H. Darwin undertook it independently a little later; and the researches of each have supplemented those of the others for more than a quarter of a century. But it must be remembered that while these two mathematicians have elaborated a highly illuminating theory, their results are to some extent inconclusive; and they are always open to the objection that the assumed spheroid is liquid and that it is homogeneous. Neither of these conditions is actually known to exist; but the stipulation has to be made in order to attack the problem mathematically at all. In Miss Agnes Clerke's [1] words they indicate rather than indite the history of systems, yet they throw the strongest light on one period of their genesis.

According to Poincaré, when the rotating spheroid quickened to the pitch of breaking asunder, it acquired three

[1] "Modern Cosmogonies," "The Fission of Rotating Spheres," "Knowledge," Nov. 1903.

unequal axes instead of two. The circle of its equator became an ellipse; and the planet became what is known as a "Jacobian ellipsoid". This shape endured for some time, a long time, but as quickening of speed and contraction due to cooling went on, even the Jacobian ellipsoid yielded. There was another crisis; another collapse of equilibrium; and before equilibrium was re-established the erstwhile spheroid had sacrificed all pretensions to symmetry and had become pear-shaped. We are now in some doubt as to the subsequent history of the revolving pear-shaped mass. M. Poincaré first pointed out that this shape was likely to split into two parts. Sir G. H. Darwin thought that the liquid rotating pear would be a stable form. Mr. J. H. Jeans, from an elaborate study of a series of revolving cigar-shaped bodies, which in theory would behave in a similar way to ellipsoids, arrived at the conclusion that in process of time the stalk end of the pear would become more bulbous, the waist would grow thinner, and a satellite would break off from one end of the parent. Sir G. H. Darwin in speaking of these and of his own researches in the mathematics of rotating fluids, remarked a curious resemblance. "The figures which I succeeded in drawing by means of rigorous calculation, of the later stages of this course of evolution, are so curious as to remind me of some such phenomenon as the protrusion of a filament of protoplasm from a mass of living matter, and I suggest that we may see in this almost lifelike process the counterpart of at least one form of the birth of double stars, planets and satellites." [1]

To sum up the foregoing paragraphs (neglecting some of the criticized and unexplained points), we may say that one method of evolution of a liquid planet and its satellite is assumed to be as follows: The revolving liquid sphere flattens to an orange shape; as it quickens it grows flatter and flatter till it approaches a symmetrical egg shape spin-

[1] British Association Presidential Address, *supra.*

ning on its side on a table. In its further development the ellipsoid becomes more and more egg shaped; and then pear shaped. One of the two ends then begins to thrust out a filament. Finally the filamentous protrusion becomes bulbous at its end, and is only joined to the main mass of liquid by a gradually thinning neck. The neck at length breaks, and we are left with two separated masses which may be called planet and satellite.

This mode of separation, this splitting or fission of rotating globes, will not apply to the separation of every planet and every satellite. The Moon's mass is $\frac{1}{80}$th that of the Earth, whereas the mass of Titan, the largest known satellite in the solar system, is only $\frac{1}{4600}$th that of Saturn; and Jupiter's third and greatest satellite contains only $\frac{1}{11300}$th part of the matter embraced in the parent body. The great relative size of our satellite affords a reason for believing that the mode of departure of the Moon from the Earth was influenced by different causes from those which operated in the lives of other planets and in the births of other satellites.

Earth and Moon

Take now the instance of the Earth and the Moon beginning their separate but joint career. They were close together. The Moon is travelling round the Earth at no great distance from it. Both spheres are spinning. Both are pulling at one another. Each is raising great tides on the other; for as Prof. Hecker of Potsdam has lately shown,[1]

[1] "Tides in the Solid Earth," by Prof. Oscar Hecker, member of the Royal Prussian Geodetic Institute, "Publications of the Prussian Geodetic Institute," N.F., No. 32, Berlin 1907. See also "Annuaire du Bureau des Longitudes," 1909, and an article in "Harper's Magazine," Vol. CXX, pp. 710 *et seq*, No. 719: —

"Our solid globe by which we mean not merely the crust, but the entire planet itself, is incessantly deformed by the tremendous disruptive attractive forces of the Moon and periodically changes its shape according to the Moon's position. This Earth which we are accustomed to regard as solid and immovable is therefore not absolutely rigid but is traversed by an elastic

even now there is an appreciable movement of the solid earth, amounting to some inches, due to the pull of the Moon. While in their early history the two spheres spun side by side, the rotation of the Earth (as of the Moon) was being slowed by the tidal wave of plastic matter that was travelling for ever round it, altering its shape. The rotational momentum which was thus being lost by one partner of the Earth-Moon system must have reappeared in some other part of the system.

A very simple illustration may be given of this. If a person taking a pair of dumb-bells in his hands, and holding them out at full length, will spin on his toes, or cause himself to be rotated on a turn-table, he may regard himself as an instance of a moving system with a certain "moment of momentum". But if while still spinning he drops his arms, holding the dumb-bells to his sides, he will find that the speed of his rotation increases. Conversely if he began the experiment with his arms to his sides, and then suddenly lifted them and held the dumb-bells out at arms' length, his speed of rotation would diminish. The reason is quite evident. Some of the particles of his "system" have either a lesser (or a greater) distance to travel: and consequently the system accordingly spins at a greater (or a lesser) speed. Loss in one direction is gained in another.

The way this acted in our system, was by the pushing back of the Moon farther away from the Earth, so that in its orbital revolution, the balance of work done was redressed. The *rotational* momentum was being lost; it was being found again in *orbital* momentum. The Moon thus retreated further and further from the Earth's surface. The "moment of momentum" was maintained by increasing the Moon's

flood tide. There is something strange in the thought that a city like London with all its huge buildings is imperceptibly rising and falling twice a day through the distance of half a yard. . . . The Earth undoubtedly yields to lunar attraction but it opposes an enormous resistance to deformation. In other words, the earth behaves like a steel ball of the size of our globe."

orbital momentum, while at the same time its spinning velocity was diminishing. Thus the Moon has retreated further and further from the Earth as the rotational speed of both orbs has been diminished by the action of their tidal pulls on one another.

[Sir G. H. Darwin has stated the case of the Earth and the Moon more concretely.[1] He describes the earliest Earth as a planet about 8000 miles in diameter, partly solid, partly fluid, partly gaseous. Its path about the Sun occupied about the same periodic time of a year then as now and its axis was inclined at an angle of about 11° or 12° to the ecliptic. It rotated in something between two hours and four hours. There was a frictional drag on its movements owing to the action of the tides which were caused by the Sun; but the Earth was cooling and as it cooled it rotated faster. The drag of the Sun's influence was not able to counteract the acceleration of its rotation; and its rapidity of spin at last became so great that it could not keep its ellipsoidal form. Then, in the manner already described, it separated and became not one mass but two; the new Earth and the Moon.]

Whether however the Moon broke off at one end, or whether, after the fashion suggested by the myriad moons of Saturn, it was at first a flying chain of meteorites; at any rate we may assume that the new-born satellite ultimately assumed a spheroidal form. At first this new Moon and the early Earth were nearly in contact with one another, and were rotating almost together. Each raised a tide on the other and the Sun raised a tide on both. In consequence of the frictional resistance to these tidal motions such a system must tend to change. How would it change?

If the Moon had moved round the Earth faster than the Earth rotated our satellite would have fallen back on the

[1] "The Tides" ("Encyclopædia Britannica"); "Roy. Soc. Phil. Transac." Vols. CLXI, CLXXII.

Earth. Therefore the Moon must have revolved about the Earth a little slower than the Earth rotated. The speed of both the Earth's rotation and the Moon's revolution will increase with time; but the Earth's rotation increases faster than the Moon's orbital motion.

The Moon we picture as a spheroid rotating at first on an axis nearly parallel to the Earth's axis of rotation. Both Earth and Moon are retarding one another's axial rotation by the action of the tides that each raises on the other. But here again the Earth's slowing is less accentuated than that of the Moon.

We have shown, therefore, various elements of instability in the system; and presently this instability manifests itself in a change.

When the speed of the Moon's orbital movement round the Earth is reduced to a point such that the orbit occupies half the time of the rotation of the Moon, the axis of rotation of the Moon begins to change. This alteration of axis becomes more and more marked, as the Moon recedes from the Earth, owing to the operation of the causes we have named; till, finally, the Moon's equator is nearly coincident with the plane of her orbit. Finally also the attraction of the Earth and the tidal deformation it caused, degenerated into a permanent ellipticity of orbit.

We need not, for the present, trace the interaction of the gravitational forces of the Earth and Moon further. The Earth and Moon system, as Miss Agnes Clerke has remarked,[1] occupies a critical situation in the solar cortège. "The planets interior to it have no satellites; the planets exterior to it (Neptune making probably only an apparent exception to the rule) have two or more. The Earth alone is truly binary; and the Moon is not only its solitary companion, but it is by far the largest companion body, relatively, to the mass of its primary, to be found in the precincts of the

[1] "Modern Cosmogonies," "Knowledge," September, 1903.

solar domain. These circumstances are certainly not disconnected one from the other, and they obviously depend on a single cause. Solar tidal friction was here the determining factor. The apportionment of satellites to the various planets was, beyond doubt, to a great extent prescribed by the degrees of retarding power over their axial rotation, brought to bear through the agency of sun-raised tides in their still plastic bodies. Hence the disruptive rate of spinning needed for the separation of satellites was never attained by either Mercury or Venus; they remained moonless for all time, and exposed, through the cutting down of their rotational velocity, to uncompensated extremes of temperature.

"How the Earth was to fare in both respects largely hung in the balance. Rightly to forecast its destiny would indeed have demanded no common perspicuity in an intelligent onlooker. Although the solar drag on its rotation had no more than one-eleventh of its power over that of Venus, it nevertheless sufficed during uncounted ages to hinder acceleration from reaching the pitch involving instability. Our embryonic planet had long ceased to be nebulous and had in fact shrunk by cooling nearly to its present dimensions before the die was cast. Then at last the hurrying effects of contraction prevailed over slowing down by tidal friction, axial speed over bare equilibrium, and the spheroid[1] divided. Now globes thus far advanced in condensation are apt to split less unequally than globes in a more primitive stage; and the Moon, because late born, was of large size. Owing to the exceptional circumstances of its birth, its considerable relative mass, or its close initial velocity, the Moon wielded over the Earth tidal influence incomparably more powerful than that exerted by its compeers in the Sun's realm." (It will be observed that in these paragraphs Miss Clerke adopted the hypothesis of Sir

[1] Apioid.

G. H. Darwin as to the splitting off of the Moon from the Earth.)

In no other satellite system that we know is the same condition of things, or the same results of it, possible. No moon besides our own possesses a stock of momentum large enough to intimate for it a similar history. The planetary attendants travel nearly in their original tracks; the fluid ripples raised by them on the surfaces of their primaries lacked power to displace them. Their own rotation seems to have been destroyed, relatively, that is, to the destroying planet; and there is the strongest probability that all the satellites of Jupiter and Saturn turn unchangingly the same face inwards. They rotate, as our Moon does, in the periods of their several revolutions: and they do so from a similar cause.

The Moon, as Prof. W. H. Pickering has remarked, is usually spoken of as the satellite of the Earth, but in point of fact it is more properly its twin. It is more attracted towards the Sun than toward the Earth, and if when situated between the two, it were suddenly stopped in its orbit, it would leave the Earth never to return to it, and drop directly into the Sun. To an observer on one of the nearer planets, Venus for example, the Earth and Moon look not unlike a beautiful double star, the Earth far brighter than Venus appears to us at her brightest, the Moon as bright as Jupiter; and the members of this binary never seeming farther apart than the distance in the heavens which (to our gaze) is covered by the Moon.

The diameter of the Moon is 2163 miles, or rather more than one-fourth that of the Earth; its mass is one-eighth; its specific gravity is three and a half times that of water, and therefore about two-thirds that of the Earth (5·6). The rather fanciful suggestion has been made that the great basin of the Pacific Ocean was once occupied by the Moon, so that the continental masses of the eastern and western hemisphere were torn asunder at the time of the separation of Moon and

Earth. A body of the size of the Moon would equal in volume a section of the Earth's crust having an area equal to the terrestrial oceans, and a uniform depth of thirty-five miles. We mention the theory without, however, any great confidence in it. It is not known that the Earth had a solid crust at that epoch, or that all the materials of which the Moon is compacted were carried off at one cataclysm, or from the same place on the Earth's surface. Moreover, there are some reasons for supposing that the Moon may have added to its size by other accretions after the separation; and the supposition must therefore remain a mere conjecture.

Conjectures which are more fruitful in the assistance they afford us in tracing the growth of a planet are those which concern themselves with the history of the Moon after its separation. It is believed that the lunar surface must have reached its present condition long before the Earth came to the state in which it became crusted over. Prof. Shaler points out[1] that when the Earth and Moon separated, the amount of heat they severally contained was roughly proportionate to the mass of each body. The mass of the Moon is to that of the Earth as one to eight, and its diameter as one to four. If, therefore, we assume that at the time of the separation, both the Earth and the Moon were in a partially liquid or gaseous state, then according to the laws of cooling bodies, the Moon must have acquired a permanent rigid crust, if indeed it did not become entirely frozen, long before the Earth ceased to have a molten surface. It appears altogether likely that the Moon cooled far beyond the point where volcanic action was possible ages before the Earth's surface could have congealed, or perhaps even before it passed from the semi-gaseous to the fluid state.

[1] "A Comparison of the Features of the Earth and Moon," by Prof. N. S. Shaler, Harvard University (Smithsonian Institution), Washington, 1903.

CHAPTER III

COOLING SPHERES

The face of the Moon—Volcanic action on the Moon—Earth and Moon craters compared—Meteoric contributions to the Moon—The Canyon Diablo crater—The Moon's seas—collision with a planetoid.

IF it be supposed that at the outset of their twin history both the Earth and the Moon were partially molten, or molten at any rate on their surfaces, then the tidal pulls set up by their mutual attractions must have produced momentous effects. While the two spheres were close together, mountainous waves of lava would have travelled over the surface of both of them. The rate of the wave movement steadily slowed, however, as the orbs receded from one another. A time would arrive when the tidal action and the dilatory movements of the viscous waves would become scarcely more perceptible than they are now; and there is no justification for believing that any of the permanent features either of the Moon or of the Earth are to be ascribed to the tidal actions of the past. The effect of the Earth's attraction, at present six times as great on the Moon as the Moon's attraction is on the Earth, and of old probably greater, would be quite competent to lift any internal mass of fluid on the Moon to a considerable height. But it cannot well have served to act as a pump to lift the lava to the elevation at which it appears frozen in the lunar craters. In order to do so the terrestrial attractions would have had to act on a central mass of igneous fluid while the crust through which the fluid surged or welled remained

rigid, not bending to any great extent. If these conditions had been possible the lava no doubt would have mounted and descended in each lunar day—and that may be almost as often as we like to reckon. But so far from the Moon's crust being then unyielding there is reason to believe that even now, with the crust of the Earth, it may yield to attraction.

According to Prof. Shaler[1] the lavas of the vulcanoid craters of the Moon froze at exceedingly varied levels. There are differences of thousands of feet in the levels of crater floors which are close to one another; and these "stations of repose" which endured long enough to permit the freezing of the lava are not to be explained on the hypothesis of incessant tidal pumping. A reasonable view of the surface of the Moon when its craters were in activity, is that it was fluid within, with a relatively thin crust. The fluid matter need not have been of the same kind as the lavas of the Earth. It was probably more sticky, more viscous, with a greater amount of pumice. The forms assumed by the lavas that have been thrust up support this view.

Before, however, setting forth any reasoned explanation of the volcanic causes which led to the constitution of the Moon's crust as we now behold it, a short description of the face of the Moon becomes desirable. A description well suited to the purpose is penned by Prof. Shaler in his "Comparison of the Features of the Earth and the Moon," from which the following passages are quoted:—

The Face of the Moon—Plains

"Turning now to the shape and structure of the Moon's crust we observe that it differs much from that of the Earth. Considering first the more general features, we note that

[1] "A Comparison of the Features of the Earth and the Moon," by N. S. Shaler ("Smithsonian Contributions to Knowledge," Vol. XXXIV, p. 31, 1903).

there are none of these broad ridges and furrows—the continents and the sea basins. A portion, the surface, mainly in the northern hemisphere, is occupied by broad plains, which in their general shape are more nearly level than any equally extensive areas of the land surface or of the ocean floor of the Earth, though they are beset with many slight irregularities. These areas of rough, dark-hued plains are the seas or *maria* of selenographers, and are called so because of old they were from their relatively level nature supposed to be areas of water. These *maria* occupy about one-third of the visible surface. Their height is somewhat less than that of the crust outside their area."

Absence of Erosion

"The remaining portion of the Moon is extremely rugged. It is evident that the average declivity of the slopes is far greater than on the Earth. This is apparent in all the features made visible by the telescope. Zöllner, by a very ingenious computation, based on the amount of sunlight reflected, estimates that the average angle of the lunar surface to its horizon is fifty-two degrees. Though we have no basis for reckoning the average slope of the land and sea bottom of the Earth, it is eminently probable that it does not amount to more than five degrees. This difference, as well as many others, is most likely due to the lack on the Moon of the work of water, which so effectively breaks down the steeps of the Earth, tending ever to bring the surface to a uniform level."

Craters

"The most notable feature on the lunar surface is the existence of exceedingly numerous pits, generally with ring-like walls about them, which slope very steeply to a central cavity and more gently to the surrounding country. There pits vary very greatly in size; the largest are more than a

hundred miles in diameter, while the smallest discernible are less than half a mile across. The number increases as the size diminishes; there are many thousands of them so small that they are revealed only when sought for with the most powerful telescopes and with the best seeing. In all these pits there is within the ring wall and at a considerable depth below its summit a nearly flat floor, which often has a central pit, or in its place a steep rude cave. . . . On the interior of the ring walls of the pits over ten miles in diameter there are usually more or less distinct terraces, which suggest that the material now forming the solid floors they enclose was once fluid; and that it stood at greater heights in the pit than that at which it became permanently frozen."

Mountains

"All over the surface of the Moon (outside of the 'seas' or *maria*) in the regions not occupied by the volcano-like structures, we find an exceedingly irregular surface, consisting usually of rude excrescences with no distinct arrangement, which may attain the height of many thousand feet. These when large have been termed mountains though they are very unlike any on the Earth, in the general absence of order in their association. They lack also the features due to erosion. Elevations of this steep, lumpy form are common on all parts of the Moon."

Cracks

"The surface of the Moon exhibits a very great number of fissures or rents, which when widely open are termed valleys, and when narrow, rills. The valleys are frequently broad, at certain places several miles in width; they are steep-walled, and sometimes a mile or more in depth. The rills are narrow crevices, often so narrow that their bottoms cannot be seen; they frequently branch, and in

some instances are continued as branching cracks for a hundred miles or more. (A catalogue of all the rills, including the slighter ones, would probably furnish several thousand examples.) It is a noteworthy fact that in the case of the rills and in great measures also in the valleys, the two sides of the fissure correspond so that if brought together the rent would be closed. This indicates that they are essentially cracks which have opened by their walls' drawing apart."

Prof. Shaler in an estimate of the heights of the outer walls and of other elevations on the Moon, inclines to the opinion that between the highest and lowest points on the Moon there may be a difference somewhere between thirty and forty thousand feet. That of the Earth from the deepest part of the ocean to the highest mountain summits is probably between fifty-five and sixty thousand feet. Therefore despite the erosion and sedimentation which diminish the difference between sea floor and mountain height on the Earth, this planet has a much greater range of elevation than its satellite. If the forces which have built the mountains and continents of the Earth had operated without the erosive action of water the difference in height would be now many times as great as it is on the Moon. The Moon and the Earth in their earlier stages probably followed the same series of changes. The epoch at which the Earth diverged in evolution from the stages of development exhibited on the Moon, was that at which water became a moulding force.

Volcanic Action on the Moon

When all the explanations of the features of the Moon's face have been examined we have to come back for illustrations to simple instances of the melting of materials known to ourselves, such as iron, or wax, or lava. We are always faced with the preliminary difficulty that the cooling of

celestial spheres may not follow the same laws of cooling, or exhibit the same phenomena. But we must (and we may) assume that for a long time after a celestial sphere has entered on its fluid state a separation of its various materials, at their various boiling-points, must go on. We may further assume that this mixed boiling of materials is likely to give rise to volcano-like or crater-like appearances. Mr. J. A. Brashear, who made some experiments reported by Prof. Pickering,[1] found that if a mass of iron slag about 4 feet in diameter and weighing about 800 lb. were allowed to cool it nearly always formed a natural crater about $3\frac{1}{2}$ inches in diameter. The crater appears only after the surface has solidified. The process of contraction aided by the occluded gases causes the liquid interior to burn through the crust and welling over the surface to build up crater walls. The fluid then subsides, leaving in some cases terraces. The floor next solidifies, sometimes again bursting through to form minute craterlets and sometimes cracks. On breaking up the slag large cavities are usually found under the craters.

The whole experiment is so illustrative and it so neatly reproduces some of the operations which we imagine to take place on the surface of a cooling sphere that we begin to suspect the plausibility of the explanation it offers. Prof. W. H. Pickering tried similar experiments with paraffin-wax, and by an ingenious pumping arrangement endeavoured to reproduce what he imagined to be the effects of the Earth-tides on the Moon. By this means, too, he made some fascinatingly plausible replicas of lunar craters and other lunar formations.[2]

[1] "The Moon," by W. H. Pickering, p. 31 (Murray), 1903.

[2] Anyone who is interested in the matter may try for himself M. Gustave Hanet's experiment. M. Hanet heats wax in a copper vessel, and when the wax begins to soften quickly plunges into it and withdraws from it a metallic rod moistened with water. The hole is then closed up and the wax heated from below again. A swelling then forms on the surface of the wax—the lava is boiling up from below—the swelling increases, and presently

One or two flaws in the illustration may be easily seen. In the first place, as we have already pointed out, we must proceed very cautiously in any analogies which depend on the tidal pull of the Earth as a first cause. The tidal pull would tend to deform the Moon's crust, rather than to draw the interior lava through it; and we are safer in supposing that this tidal pull was merely of assistance to volcanic action in forming, or helping to form, cracks in it. A volcano is primarily a crack in a planet's crust. The Moon's crust must at one time have been very thin, and the boiling interior must have broken through it with ease.

A second flaw in the analogy is the nature of the boiling or bubbling. It must again be repeated that the pull of gravity of the Moon itself on its own materials is comparatively small, and this would influence alike the escape of gases and the movements of boiling liquids on its surface and in its interior. The Earth, we are quite sure, did not cool to anything like an even temperature through and through before a crust was formed on it. But in the lighter mass of the Moon, it is possible that the boiling and bubbling went on so long that when it ceased the whole of our satellite was at a temperature not much above the heat of its lava, so that the further cooling would be uniform. There are objections to this theory, but it does appear probable that the whole mass of the Moon became solidified at nearly the same time and temperature.

Earth and Moon Craters Compared

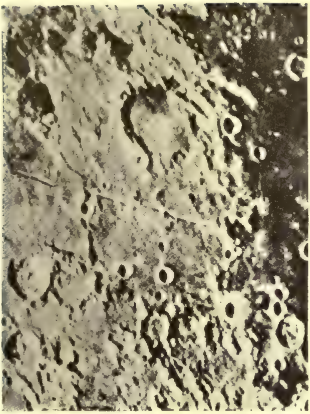
On the Earth there are no craters comparable in size to the great and older craters of the Moon. These craters were probably formed in the youth of the Moon, at a time

bursts. A jet of steam escapes and the swelling subsides in the form of a ridge with vertical walls. By this action of the occluded steam the mass has been relieved of pressure for a time, but after a short interval a similar series of phenomena will be repeated.

when the crust had become solid but was very thin, and was continually being cracked and opened. If there ever were any craters on the Earth formed during its early history under similar conditions they have been obliterated by subsequent events, for all those of our craters now existent, or traceable, are of the explosive type, and of the cinder cone type. Lava craters, where the lava occurs in unbroken masses, are rare: though there is a very good example in the Hawaian Islands—Halealka, in the Island of Maui, measures about seven miles in length by two in width. It is about 2000 feet deep. There is also an extinct engulfment crater now filled with water and known as Crater Lake, Oregon, which has an area of thirty square miles and is 3000 feet deep. These dimensions are minute compared with Clavius on the Moon, which measures 143 miles in diameter and has a depth of two and a half miles, or of Shickard, 134 miles in diameter. But in Hawaii the formation of these crater and lava rings can be watched, and they apparently form a very good guide to the formation of the similar rings on the Moon. We quote some psssages from Prof. W. H. Pickering's "Lunar and Hawaian Physical Features Compared"[1] to illustrate the process of crater ring formation:—

"Halemaumau, known as the pit, is the centre of volcanic activity in Kilauea. When the pit of Halemaumau is emptied it is always through some subterranean passage occasionally reaching the surface. The eruptions are occasionally accompanied by slight earthquake shocks. When the "pit" is really active, lakes of liquid lava occur both within and without it. Numerous fire fountains, fifty feet in height, play over the surface of these lakes. At times the surface solidifies, then suddenly a crack will run across it, and in a few minutes the whole solid material will break up into separate cakes which will presently turn on edge and sink beneath the surface of the lake. This again solidifies

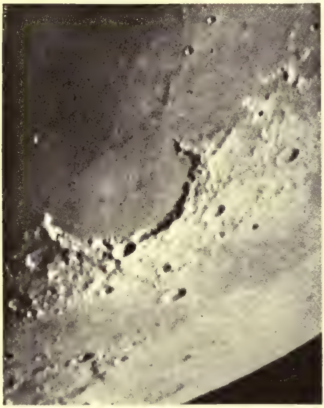
[1] "Memoirs of the American Academy," Vol. XII, April, 1906.



A RILL ON THE MOON
(Ariadeus)

RING CRATERS AND LAVA BLOCKS ON A LUNAR SEA
(Mare Imbrium)

TWO LARGE RING CRATERS ON THE MOON
(Schickard: Phocylides)



RING CRATER BY A LUNAR SEA
(Sinus Iridum)

(By permission of Professor W. H. Pickering)

and the process is repeated. (These lakes form the analogy on which we base the theoretical construction of lunar crater rings.)

"On 2 April, 1868, a severe earthquake shook the southern coast of Hawaii, and for the next five days a subterranean discharge of lava took place from Kilauea. As a result of this discharge the central area to the north-east of Halemaumau sank about 300 feet carrying into it the vegetation still growing on its surface. The lava also flowed out of Halemaumau leaving a circular pit 3000 feet in diameter at the top, 1500 feet at the bottom and 500 feet deep.

"A year later Halemaumau had filled to within 100 feet of the top, the level area within it showing eight small apertures within which the liquid lava could be seen fiercely boiling. A few months later the lava was within 25 feet of the rim and the diameter of the pit had enlarged to over a mile.

"In the next year the pit overflowed, the lava pouring out and down and partly filling the north-eastern depression. At the time of an eruption such as this, the lava rises, overflows and cools, then forming a raised rim or circular dam. Such it is suggested is the method of formation of the Moon's crater rims.

"The outside height of the crater rings in Halemaumau rarely exceeds 15 to 25 feet. The inside height is constantly varying with the fluctuating level of the surface of the lava lake. When the outside height becomes too great to withstand the internal pressure, the rim gives way, the lava breaks through and floods the surrounding regions. By means of this successive building up and flooding, the whole region around Halemaumau was elevated until the walls became too high and too thick for the floods to escape over or through them (or the flow might have been elevated by pressure)." We need not trace all the analogies by which

Prof. Pickering endeavours to explain the formation of lunar craters and volcanoes of various kinds; it will suffice to say that he makes out a very strong case for supposing that the visible remains of volcanic action on the Moon indicate that it was most frequently of a slow boiling character. The great craters at any rate are not the relics of great explosive volcanoes. We may argue, therefore, that similar processes took place at one period on the earth. The reason that the crater rings are so numerous on the Moon and so rare on the Earth is that the terrestrial ones are not generally permanent, a result partly due to differences in material, and in the action of gravity on the material, as well as to the effects of ages of erosion.

Meteoric Contributions to the Moon

There is another conspicuous feature of the Moon's surface which affords room for ingenious speculation on the possibilities of planetary growth by additions from outside. A very large number of meteoric bodies of varying sizes fall on the Earth during the course of the year. It has been estimated that some hundred thousand of them impinge on the Earth's atmosphere every day, though nearly all are so small that they are burned by friction and are added to the planet only as dust that descends in the rain or as gases contributed to the air. It has been suggested that a great number of these meteors are merely the returned contributions which the great extinct volcanoes of the planet's youth hurled beyond the immediate attraction of gravity into space, and that we continue to pick them up in our circumambulation in the solar system. But no theory of the primary solidification of parts of the solar system into planets can neglect the extreme probability that every planet must have added to its bulk by the addition of smaller bodies and of bodies less stable in their orbits than itself. Thus if for millions of years the planet had been accumulating merely

cosmic dust, yet many millions of particles of no more than a millimetre in diameter would in the course of time have made a considerable addition to the planet's bulk.

We are warranted in assuming, however, that some of the meteors which have reached the Earth have been of very much larger size. According to Prof. Berwerth, of Vienna, the number of meteorites of noticeable size which fall on the earth each year is about nine hundred. With regard to the size of meteors which have fallen within recent geologic time, we may cite the gigantic Cape York iron meteorite discovered by Commander Peary and weighing 37½ tons: the Williamette iron found lying in a primeval forest and weighing 15 tons; and the Bacubirito iron weighing at a rough estimate 20 tons. There is one region where a meteorite or meteorites fell, which seems to point to the impact of a very much larger body than any of these.

Canyon Diablo Crater

Not far from Canyon Diablo[1] in Arizona, is a remarkable crater-form depression. It exists in a region where there are no other signs of volcanoes or any suggested origin for volcanic action. The crater, some three-quarters of a mile in diameter and 500 feet in depth lies in a region of undisturbed water-borne rocks. As seen from the railway and from other points within a few miles of it, the crater rim rises above the level of the plain in the form of a low hill with peculiarities of contour and surface configurations which at once catch the eye. A nearer approach discloses the hill as a low circular ridge or rim surrounding a pit. The ridge or crater rim is on an average about 140 feet above the surrounding plain and its diameter is about 3900 feet. The level of the plain inside the crater is approximately about 600 feet below the

[1] For a further account of this region, see article by G. D. Merrill, "Smithsonian Miscellaneous Collections," Vol. L, 1908.

crest of the surrounding rim. Indeed the crater as a whole is not unlike some of the smaller lunar craters, though it is itself smaller than any we can discern on the Moon.

Its constitution and surroundings, however, put the question of volcanic or lava-like formation out of the question. The crater rim is composed on its outside of loose fragments of material, mostly angular and beyond question derived from the sandstone interior of the crater. These fragments range from fine rock dust to masses of sandstone weighing hundreds or even thousands of tons. Some of the larger blocks are of hard limestone which does not weather so fast or so easily as the sandstone. Perhaps the most significant feature of the masses of scattered débris, which spread out in gradually diminishing quantities to distances as great as a mile from the crater's rim, is the occurrence of enormous masses of sandstone which have been partly crystallized through crushing and heat. The interior walls of the crater consist chiefly of stratified limestone and in a less degree of sandstone, both of which have been crushed and shattered to an extraordinary degree. The walls are steep, often overhanging, and so crumbly as to make exploration dangerous. Beyond the fringing reef of rock material the floor of the crater presents a nearly level plain 300 acres in extent. It needs but a glance to see that its depth, now 440 feet below that of the surrounding country outside, was once considerably greater, and has been filled up by rock falls and blown sand.

As long ago as 1896 it was suggested that the crater-like depression, which viewed from a balloon would resemble the splash of a projectile on a steel plate, had been caused by the impact of a meteoric fragment of great size. The whole neighbourhood is sown with meteoric material, specimens of which can be seen at the Natural History Museum in Cromwell Road, and other specimens of which became famous because they contained minute fragments of diamond. The exact number of masses of meteoric iron which the

district has yielded can never be known because for a number of years a local trade has been done in them. But twenty tons of material and many thousands of specimens, ranging from the 1000 lb. block now in the Chicago Museum, is a modest estimate.

Nearly all these meteoric irons lie outside the crater, in the surface of the ground, at distances as great as several miles from it. An examination of the crater floor by borings descending to 1100 feet has revealed a series of layers of a lake-bed formation, all more or less metamorphosed by heat and pressure. Below 800 feet the borings found yellow and red sandstone, comparatively soft and not changed by heat. (This seems definitely to disprove a volcanic origin for the crater.) The borings below 180 feet and down to 600 feet continually encountered samples of meteoric metallic material.

So far as shape of the crater is concerned it might equally well have been caused by a volcanic blow-out or by the impact of a great meteoric stone. But the sandstone at 800 feet depth is fatal to the volcanic theory, while the upper layers below the crater plains show the presence of diatoms and fresh water molluscs and indicate that the bottom of the crater was at one time occupied by a shallow lake which accumulated lime and gypsum deposits during periods of drought. The chief difficulties in accepting the meteoritic hypothesis lies in our ignorance of the depth to which a falling meteorite would penetrate.

The estimate which was made by Mr. Merrill of the circumstances which attended the crater's formation can only be regarded as speculative. He imagined that the crater might have been formed by the impact of a mass of meteoritic iron, perhaps 500 feet in diameter, falling on the earth at a speed of five miles a second. By comparison with the splashes made by steel projectiles on armour plate the splash thus formed would be eight to ten times the

diameter of the projectile, that is to say the crater would be about 4000 feet in diameter. As it penetrated the earth, the rocks directly in its path and round about it would become very much compacted. The heat generated would melt some of them to the point of converting them into gas; and if there were water present would change some of the sandstone to pumice. There was water present, as other features show, and this would be suddenly converted into steam of an enormous explosive power. As a result masses of débris, and even of the meteorite itself, would be blown far and wide; and something approaching a temporary volcano would be formed.

The Moon's Seas

Prof. Shaler has endeavoured to show that in certain features of the moon—the *maria*, or so-called lunar seas—we see the relics of similar concussions on a very much larger scale. A large part of the Moon is occupied by extensive, irregular, indistinctly circular areas, which are relatively level and of a darker line than the other more rugged fields. Small craters are found on them but they are few in number. The plains of the Moon are apparently more nearly level than any equally extensive land areas on the Earth. If these plains are formed of lava they appear to have flowed over or against their boundaries of rougher ground, and to have submerged some of the older formations which bound them. Prof. Shaler points out that there is no evidence that these lakes of lava came from a central pipe or fissure; and there is no slope such as we might expect from the centre of the field to its margin. On the Moon we should expect this slope to be steep in order to induce the flow, because the force of gravity is small; but this appears not to be the case. The plains are horizontal.

Prof. Shaler is, therefore, inclined to adopt the hypothesis that the *maria* are the result of large masses falling

LAVA LAKE IN KILAUEA

VOLCANIC CRACK IN KILAUEA: SUGGESTING A RESEMBLANCE TO MARTIAN CANALS AND LUNAR RILLS

(From Prof. W. H. Pickering's "Lunar and Haiwaiian Physical Features")

upon the surface of the Moon. "All the facts indicate that these vast sheets of lava did not come from the interior, and that the interior at the time when they were formed was not in a condition to yield any such masses of liquid rock. . . . Assuming that a mass of rock or meteorite some miles in diameter came upon the surface of the Moon at a velocity of some miles a second, the heat due to the arrest of its movement would convert the whole of the body into a liquid if not into a gaseous state. A like result would occur in the part of the sphere which received the blow. It seems also fair to suppose that a great collision of this nature would temporarily form a heated atmosphere enveloping the Moon and serving to delay the cooling of the molten rock till it had time to find its level. . . ." Moreover, these plains of lava seem always to have been the result of one flow. There are no signs of successive flows such as have always characterized the much smaller lava plains formed in the Earth.

Prof. Pickering has made the alternative suggestion that just as in a piece of cooling slag there are hollows beneath or near the surface eruptions; and just as there are probably subterranean cavities beneath the lava pits of Hawaii, so there were great cavities found beneath areas of great volcanic activity on the Moon. These cavities would in many cases unite and would thus cover considerable areas leaving large empty spaces beneath the outer crust and the hot material of the Moon's interior. Should the partition walls between some of these cavities give way, large areas of the outer crust might be precipitated on the partly-liquid mass beneath. These great cakes or slabs would sink and melt, and a fresh lunar surface would be formed in their places. It is not of great importance whether this subsidence was gradual or cataclysmal. One piece of evidence favouring this view of the origin of the *maria* is that their level is lower for the most part than that of the regions surround-

ing them. The theory does not, however, account for the colour of the *maria*, which is darker than that of any other surfaces of the Moon. Moveover, it does not explain the distribution of the *maria;* and whereas we should expect to be able to trace some stages of evolution between the larger craters and the lava formations which, according to the theory, were the outcome of their breakdown, we find on the contrary that in nearly every characteristic they are sharply distinguishable.

At the same time objections must be considered to the meteoritic theory of the *marias*' origin. Of these the first is derived from the fact that bodies capable of producing such effects have not fallen on the Earth in the time which has elapsed since the geological strata were laid down. In fact, geological history gives us no reason for supposing that such bodies have ever fallen on our planet. Against that we may set the consideration that the Moon's face probably was frozen long before the Earth's geological record began. The fact must also be considered that even in this late stage in the evolution of our solar system there remain bodies large enough to produce the effects noted if they fell on the Earth or the Moon. The group of asteroids which lie between Mars and Jupiter, though most of them are of far greater mass than would be required to produce these effects, probably contains smaller bodies which would produce such a phenomenon. The planetoid Eros, which is one of the later additions to astronomical knowledge, is of no great distance from the Earth; and it is probable that in the earlier years of the solar system these detached masses of matter were more abundant than they are at present. A mass of the size of the planet Eros coming into collision with the Earth would produce a temperature high enough to shrivel all organic life on the Earth. Life would have to begin again. The geologic record contains nothing to lead us to suppose that this has happened, though evidently if such

a catastrophe occurred long enough ago the subsequent epochs in the world's evolution would have masked the occurrence beyond recognition. Perhaps the meteorite, if meteorite it was, which produced the crater of Canyon Diablo, afforded a demonstration of such a cataclysm on a reduced scale, and was the origin of the desert conditions of the neighbouring lands.

CHAPTER IV

PLANETARY ANALOGIES

Atmospheres of Planets—Jupiter and Saturn—Mercury and Venus—Mars—Martian canals and their significance—Mars and the Earth.

A GOOD deal is known of the physical condition of the Moon, and tentative as are the speculations concerning its origin it remains the only sphere other than our own on which we can base any valid conclusions concerning planetary evolution. Neptune and Uranus yield hardly any information to the photographic plate, beyond that of enabling measurements to be made of their positions. The analysis of the sunlight reflected from them affords some data of their atmosphere; but the spectroscopists are not agreed concerning the inferences to be drawn from the observations. Yet they supply clear proof of the existence of an atmosphere in Uranus, and probably free hydrogen and possibly water vapour may exist there. Photography has not hitherto been an efficient implement of research with these distant planets; and even in the case of Saturn and Jupiter the best portraits are those which have been drawn from visual observation. The best defined photographs extant of Jupiter are those which have been taken by Professor Hale at the Mount Wilson Observatory. They, however, show little more than the bands which encircle the planet and disclose little or nothing of its other characteristic features.

[1] "A History of Astronomy," by W. Bryant, p. 238 (Methuen).

Saturn with its rings, and its nine moons, of which the last discovered, Phoebe, revolves about the planet in a direction opposite to that usual in the solar system, suggests many problems in celestial mechanics; but there is nothing known of its history which would be pertinent to the study of a planet's growth. The rings which surround it were one of the celestial phenomena which at one time were assumed to favour the Laplacian theory that rotating molten masses flattened till they reached a point of unstable equilibrium and then threw off relief rings in order to restore a stable relationship between their contracting mass and their speed of rotation. Lowell[1] recently drew attention again to beads on the rings which, as Struve and Proctor thought, are points of collision of the fragments of matter composing them; and suggested that in the course of ages these collisions must bring about such a diminution of speed in the moving particles, that they would fall on to the planet. Such an occurrence might have been a stage in the history of more than one planet, but it seems too exceptional to be so regarded. It is by no means safe to suppose that there is no tendency to variation in the history of inorganic matter or masses of matter; and it must not be rashly assumed that, for example, since Jupiter is hotter than the Earth, and the Moon is colder, therefore the Earth has advanced from a stage similar to that of Jupiter, and will ultimately reach the condition of the Moon. The evolution of a planet is dictated to a very great extent by its size; and it would be a very uncertain assumption that Jupiter's history will resemble that of the Earth; while it is almost certain that the past history of the Moon, during half the period of its existence, has differed radically from that of the Earth. It is extremely improbable that the Moon ever had an atmosphere of any perceptible amount, because the attraction of its gravitative force was never sufficient to neutralize the

[1] "Scientific American," 10 December, 1907.

outward flying tendencies which characterize the molecules of atmospheric gases.

Atmospheres of Planets

All the molecules of gases are in rapid movement; and the rarer a gas the greater the average velocity of these particles. The speed of some of the molecules must be considerably greater than the average, and probably at some time in its history every molecule attains the greatest speed of which it is capable. Now for each planetary orb there is a speed which would suffice to carry a molecule away from that orb; and the rule is that the greater the orb, and the greater its gravitative attraction, the greater would have to be the speed of the molecules in order to get away. Conversely the smaller the orb the smaller the speed of the escaping molecules would have to be. The speed which a gaseous molecule would have to attain to fly away from the Earth would be 7 miles a second: from Venus 6·2 miles a second: from Mercury 2·9 miles a second: from Mars 3·2 miles a second from the Moon 1·5 miles a second. Thus the heavier the planet the rarer the gas it can retain. If the Moon had been able to hold an atmosphere, there is no reason why it should not have had the history of a miniature Earth. "As it is, from the beginning it appears to have been determined that it should have no share in the solar energy which awakened the organic activities of the Earth; and there is no imaginable accident that can alter its state except some catastrophe which may return the solar system to a nebulous mass. Just as it is our Moon is likely to see the Sun go out."[1]

Jupiter under favourable observation discloses a planet which is apparently covered by a gaseous envelope or overlying cloud strata. The planet has many conspicuous and

[1] "A Comparison of the Features of the Earth and the Moon," by N. S. Shaler, p. 75.

variable markings, spots, and bands, or belts. Mr. Stanley Williams has differentiated the belts and zones, separating the regions of Jupiter, for example, into Equatorial Zone, North Equatorial Belt, South Equatorial Belt, North Tropical Zone, North Temperate Belt, South Tropical Zone, South Temperate Belt; and has distinguished nine principal currents in different latitudes. But these currents do not necessarily travel faster nearer the equator; and several other inconsistencies and unexplained phenomena are presented by the markings of the planet. The great red spot which in various stages of intensity is seen from time to time between the equatorial current, and the south temperate current is one of the most puzzling of the features of the planet. In actual section it is several times larger than the Earth; but it is not possible to say whether it is an island floating as it were on the surface of a liquid planet, or whether it is a part of the planet which is from time to time obscured. In Mr. Stanley Williams' collected observations [1] he remarks that under conditions when Jupiter can best be seen the whole spot showed a complicated structure of delicate details. It used to be thought that the light regions of Jupiter represented the upper surface of a cloud envelope frequently illumined by the sun; while the dark markings were due to gaps in this cloud envelope permitting the solid and darker surface of the planet to be seen. But the later opinion is that there is no great difference of altitude between the surfaces of the light and dark bands as we see them. It is also surmised that the great Jovian currents of matter—of whatever character the matter is—flow side by side, at differing velocities, and that possibly material from one current occasionally breaks into another current. But this apart from detail, and apart from speculation, is the only material which Jupiter affords us for the study of the development of a planet.

[1] "Zenographical Fragments," Vol. II, "The Motions and Changes in the Markings on Jupiter," by Mr. Stanley Williams (1909).

The most we can speculatively infer from its appearance is that at a stage much cooler than that of the Sun, a rotating sphere begins to differentiate its materials and to display a more sluggish periodicity in what may be called spottiness. By that term is meant the appearance of phenomena resembling the spots which appear from time to time on the surface of the Sun.

MARS

Of Mercury and Venus [1] the observational knowledge is even more scanty than that of Jupiter or Saturn. Mars alone remains as a planet which may enable us to pursue the study of an evolution similar to that of the Earth; and during the last thirty years it has been the arena, almost the battlefield, of unending discussion. Mars is a sphere which has a diameter only half that of the Earth, a density only three-fourths as great, and a mass not greater than one-ninth that of our orb. Any gas, the molecules of which were moving at a mean rate of a little over three miles a second, would leave the planet sooner or later; and,

[1] Prof. Lowell believes that the atmosphere of Venus is cloudless and he has made diagrams of markings on it. The late Mr. R. A. Proctor declared it to be surrounded by a cloud envelope (perhaps snow cloud) and from observations made during its transit of the Sun inferred that it had very high mountains. Prof. Pickering regards it as covered by ocean and cloud. Of these observers Lowell is the most positive. He writes: "In 1903 I observed Venus from 18 February to 26 July. In view of the difficulty of the subject and the possibility of psychical illusion I took special care in my scrutiny of the markings presented by the disc." In his illustrative diagrams two lines like a V turned on its side seem to radiate across the disc of Venus, and there is what he calls a "collar" about the North Pole. He adds that there are lines to be seen in Mercury. "Its lines, more difficult than the canals of Mars—for we see Mercury four times as far off, when best placed, as we do Mars—though roughly linear are not unnatural in appearance even at that great distance, and show irregularities suggestive of cracks. In the markings on Venus, too, there is nothing unnatural." "Mars as the Abode of Life," pp. 178, 182. 193 (1908); "The Planet Venus," a lecture at Clark University, by Percival Lowell. "Popular Science Monthly," Dec. 1909, pp. 521-31.

therefore, on theoretical considerations the atmospheric envelope of Mars should be slight. It should be hardly more than one-seventh the density of that of the Earth. The strongest piece of confirmatory evidence in support of this hypothesis is that details of the surface of Mars can be seen very clearly, though clouds or vapour, or what Prof. Lowell describes as mist, become visible from time to time. As long ago as 1882 Maunder proved that the atmosphere at the surface of Mars is as rare as it is on the tops of our highest mountains. The aneroid barometer on Mars would seldom register higher than four inches.

Except in the winter time, or after the melting of the polar snows of Mars, nothing seems to stand in the way of an uninterrupted view of the Martian surface, whether in the Arctic, temperate, or tropic zones. The great clouds which sometimes have been seen to cross its surface; and which indicate an atmospheric circulation on Mars similar to the great air currents of the Earth, have been attributed not to particles of water but to dust. It is possible that the mistiness which occasionally obscures details of the surface is due to the formation of fog. Particles of dust (or of carbon, as in the unconsumed smoke of cities) will act as the foundation of fogs. Owing to the feeble gravitation of Mars atmospheric movements must be languid. Another kind of mist perceptible on Mars is ascribed by Lowell to the melting of the polar snows. It is most evident on the fringe of the polar caps. In these Arctic regions snowfalls of long continuance occur.

Prof. W. H. Pickering noted in 1890 two storms which spread over the polar circle, the first of which lasted two weeks, and the second of which began to clear only after forty-one days. Pickering also adds an observation which confirms the impression that the clouds of the more temperate regions are not vapour clouds such as are characteristic of the Earth's atmosphere. Their colour is always of a light

yellow. It is noticeable that the snow of the polar caps often has a yellowish tinge.

Martian Canals and their Significance

Of all the characteristics of Mars none has presented so much opportunity for controversy as the so-called system of "canals". The face of Mars has both dark and light areas; and it was at one time believed that these were sea and land. But there are no oceans on Mars; the most delicate spectroscopic investigations for a long time failed to show that there was any water vapour in the planet's atmosphere, and its existence cannot now be taken as proved.[1] The dark areas might be old sea-bottoms; the light ones, desert land. Both sea bottom and desert are crossed by a number of markings which appear to be straight lines. Special attention was first drawn to them by Schiaparelli in 1877, and the Italian astronomer called them channels,—a word which was interpreted to mean canals in the artificial sense. The observation of these "canals" has been pursued by astronomers, but by none with more persistence than Lowell at Flagstaff Observatory, Arizona, and his assistants Mr. Lampland and Mr. Slipher. Mr. E. C. Slipher made an expedition to South America during the opposition of Mars in 1907 to photograph the planet. On the plates the larger "canals" are seen clearly and in one instance the plates show a pair of "canals" running parallel to one another. Under the observations made by these and by

[1] F. W. Very (Lowell Observatory Bulletin, 1909, No. 36), reaffirmed its existence from spectroscopic evidence and gives its mean value as about one-fourth that of the Earth.

Prof. W. W. Campbell, Director of Lick Observatory, reaffirmed in 1909 his belief that there was no satisfactory spectroscopic evidence of the existence of more water vapour in Mars than is present on the Moon ("Science," 26 March, 1909).

See also Dr. C. E. Abbott, "Smithsonian Miscellaneous Collections Quarterly Issue," Vol. V, Pt. IV, p. 506.

other astronomers the number of "canals" on the planet has reached a considerable figure. Prof. Lowell speaks of them as innumerable to skilled vision; but 522 of the more noticeable have been catalogued.[1] Fifty-six of these are described as "doubled canals". A large proportion of these run to junctions, which were first called "lakes," and are now known as "oases". These are apparently self-contained and self-centred. They are small, dark, and as nearly as can be made out, round.

The foregoing statement of the appearance of the face of Mars will enable anyone to comprehend the interpretation of it which has been offered by Lowell. He regards these lines on the planet's surface as artificial; and he assumes that they were made in order to convey water from one part of the planet to another. They are, in short, the features of a vast irrigation system, which has multiplied in magnitude and complexity as the water of the planet has failed, and which may have occupied many centuries, or ages, in the making. Their function at present is to convey water from the melting snow of the poles in the spring time; and so to enable the vegetable life of the planet to continue. One point in dispute about the canals is their invisibility from time to time. They appear and disappear; and, according to the critics of Lowell's theories, the maps which have been made of them from time to time are not in agreement. The appearance and disappearance of the canals, according to Lowell, is attributable to the extent of vegetation which is advantageously brought into existence by them, for what the observers see is not the canal itself but the fringe of plant growth which it irrigates.

Such is the theory, and it assigns to the planet Mars the existence of a race of intelligent beings, who either now, or at some previous stage in their history, possessed engineering ability of a very high order. It is not necessary here to

[1] "Mars as the Abode of Life" (1908).

weigh all the evidence for and against Lowell's theory of an intelligent activity on the territories of our neighbour.

Lowell's argument assumes in effect that no marking on Mars can in reality possess any irregularity in form or outline unless he, or his assistants, have perceived such irregularity in it. But as early as 1891, long before Lowell began his study of the planet, Maunder had learned, from his observations of sunspots with the naked eye, that markings, no matter what their true form, below a certain limit of size, can only be perceived as straight lines or circular dots; Lowell's "canals" or "oases". In a paper published in "Knowledge" in 1894, Maunder applied this principle to the interpretation of the Martian markings, and ten years later in a series of experiments conducted with the boys of the Greenwich Hospital School, he illustrated the way in which, under given conditions of angular amplitude, details however irregular and unsymmetrical, present themselves as geometric straight lines and circular spots. The Martian "canals," in the main, therefore, represent actual markings on the planet, but their artificial appearance, as if they were geometrical figures drawn by pen, ruler, and compass, is due simply to their small angular dimensions, which prevent their real irregularities from disclosing themselves. The controversy on this side is now, indeed, over; a sufficient number of the linear "canals" of Lowell have already been shown by more powerful telescopes or more acute observers to display such irregularities of shape, breadth and direction as to fully refute Lowell's contention that their regularity proves their artificial origin.

Prof. Simon Newcomb has further shown that the canals already recorded by Prof. Lowell account for nearly two-thirds of the entire surface of the planet. Prof. W. H. Pickering has stated that the belief most generally held by astronomers is that the canals are due to volcanic cracks lying between craterlets on the Martian sur-

face.[1] Water vapour escaping from these craterlets and cracks nourishes the vegetation growing along their sides, and it is this vegetation which is visible to the world's telescopes.

This latter view has the advantage that it also explains some of the "canals" on the Moon which, as seen through a small telescope, are very like those to be observed on Mars. Pickering adds that they go through similar changes in the course of the long lunar day to those that the Martian canals exhibit in the course of the Martian year and differ from them only in the fact that they are on a much smaller scale. Through a large telescope and with very good atmospheric conditions for seeing, the craterlets and cracks about which the lunar lakes and canals are formed can be distinctly seen, and the gradual transformation of a crack into a canal has been watched and the rate of growth measured.[2] Through a small telescope the lunar canals, like the Martian ones, appear straight and perfectly uniform. Through a large glass, on the other hand, irregularities of outline appear and marked variations in the depth of colour. Similar high small vegetal canals, found about the terrestrial volcanic cracks, have been photographed in Hawaii in the great plain extending to the South of Kilauea. The only vegetation on this plain consists of trees, low bushes and ferns, which stretch across it in long narrow straight lines, following the course of the steam cracks whose exhalations furnish the necessary moisture on which the existence of vegetation

[1] See also E. M. Antoniadi, "Nature," 5 January, 1911, p. 305:—

"On 21 September, 1909, I state that those geometrical spiders' webs do not exist ('Journal of Brit. Ast. Assoc.,' Vol. XX, p. 141).

On 3 January, 1910, Prof. Hale proclaims the perfectly natural appearance of the planet in the Mount Wilson 60 in. reflector, by far the most perfect and powerful instrument yet made, and the total absence of straight lines ('Journal Brit. Ast. Assoc.,' Vol. XX, p. 192)."

[2] "Annals Harvard College Observatory," LIII. 79. "Memoirs American Academy," 1906, XIII. 176.

depends.[1] It may be urged that these instances, on account of the small dimensions involved, are not to be compared with the Martian canals, which stretch for hundreds of miles, and which show such a definiteness of arrangement that it is a violation of the law of probability to believe it to be accidental. It is also urged by Prof. Lowell and his assistants that they who have watched the canals over a number of years, under all conditions, and by observations repeated thousands of times, are not likely to be misled by visual illusions; but that on the contrary their repeated observations have established positively the regularity of the arrangement of the canals, and, in consequence, the plausibility of some theory of design in their construction.

Mars and the Earth

Of the two views it is possible only to say, in the absence of more precise information, that while there is a probability of life of some kind on Mars, and a considerable probability of vegetable life, yet the existence of intelligent beings there demands more evidence than has hitherto been furnished. The law of probabilities, which Lowell seeks to apply in order to add force to his convictions, can only be applicable when the factors of the computation are unassailable, in other words, when the objective reality of the principles of design in the canals is completely demonstrated; and that we do not think yet to be the case. But we may examine with interest the other aspect of Prof. Lowell's propositions. The physical conditions on Mars are in many ways intermediate between those found upon the Earth and the Moon. One inference to be drawn from that is that the life existing on Mars should be of a lower type than that which is fostered by the abundant air and water of the Earth. That, however, is not Lowell's hypothesis. In his

[1] "Hawaian and Lunar Physical Features Compared," by W. H. Pickering, p. 178.

view Mars cooled much sooner than the Earth, because of its smaller bulk and in consequence is, as a habitable globe, much older than the Earth. "It has long since passed through that stage of its planetary career which the Earth at present is experiencing, and has advanced to a further one to which in time the Earth itself must come, if it be not overwhelmed beforehand by other catastrophes. In detail, of course, no two planets of different initial mass repeat each other's evolutionary history; but in a general way they severally follow something of the same road."

A future which Lowell foresees for the Earth is, therefore, one in which it must suffer, as Mars apparently has done, the loss of its oceans, seas, rivers and other reservoirs of water. Its waters must retreat towards the interior of a cooling planet through the crevices and fissures, great and small, of its surface. In addition to this, evaporation is continually taking place over any liquid surface, so that its molecules are always being lifted into the air, and the speediest of these when they arrive at the confines of the atmosphere take flight from it into interplanetary space—therefore first the lighter gases leave a planet, then some portions of the heavier gases, including the gaseous constituents of water. "These stages in the inevitable parting with its hydrosphere are exemplified to-day by the Earth, Mars, and the Moon. On the Earth the sea bottoms still hold seas; on Mars they only nourish vegetation; on the Moon they contain nothing at all." Lowell goes on to assert that loss of water has been going on through the æons that have passed on the Earth, and that the process is taking place under our eyes to-day—the land is gaining on the water, deserts are widening, the rainfall tends to diminish along the semi-tropical belts. In some future which we may not be able to compute, but which is inevitable, the Earth, slowly drying, must become a planet of Saharas, comparable in aspect to those exhibited to us by Mars, and

greater in size as the Earth is greater than its arid neighbour.

Prof. Lowell's gloomy forecast begs a great many questions. The critics of his views are not astronomers alone, among whom he speaks as to people of equal knowledge of the subject, but geologists who are better qualified than he to judge of geological evidences of the permanence or disappearance of the waters of the globe. Prof. Eliot Blackwelder has pointed out that there is no evidence that the land of the Earth has grown at the expense of its waters.[1] There have been fluctuations of land and sea throughout recorded geological history, and these changes show no general tendency. Deserts have existed in many parts of the world ever since the earliest periods wherever the topographic and atmospheric conditions were favourable. It is not probable that our present deserts are more extensive than those of the Permian period, during which the saltest of salt lakes covered the site of Germany. The theory which has found most acceptance both with geologists and physicists is that there has been an unceasing oscillation of land masses and of water areas. Many causes have been suggested for this, some of which we shall have to consider; the most plausible of them appears to be that which has imagined an advance, alternating with a retreat, of the oceans to and from the poles.

[1] "Science," 23 April, 1909, p. 659.

CHAPTER V

THE CORE OF THE EARTH

PART I

The gaseo-molten planet of Laplace—The Earth's primal crust—The primal gases—Objections to the theory—The alternative or planetismal hypothesis—Attraction and retention of an atmosphere—Heat of the first nucleus—Volcanic action of a growing nucleus—The hydrosphere.

PART II

The older hypotheses of a cooling Earth—Internal heat of the Earth—The level of no stress—Solidification from the centre—Melting-points of rocks under pressure.

PART III

Distribution of heat in a planetismal Earth—Underground temperatures —Prof. Joly's theory of radio-active heat—Seismology and theory.

PART I

THE foregoing sketch of the events which may have accompanied the birth of a planet leave us still a long way from solid ground. The several stages of the planet's development which took place before the rocks were laid down have yet to be considered. Such stages, like the earlier ones which have already been under consideration, are far from being proved realities, and theories about them must be entertained with reserve. But it is necessary to frame some hypothesis which will embrace them, because it was during this period that the planet became a solid whole and that new forces arising from its solid condition were brought into play. It was during these stages that the Earth's shape and its configuration in the larger sense, were determined.

The Gaseo-molten Planet

In the preceding chapters the type of development which has been prominently under consideration has been that of a partly molten sphere which has cooled down, and which has solidified as it has cooled. But we have always kept in mind a variation of this process, or an addition to it. When the primal nebula of a solar system first took the form of a double spiral, and knots or nuclei appeared on its extended arms there was still a vast amount of unappropriated nebular matter; and we supposed that this matter was attracted to the nuclei, which thus grew continually larger, and more powerfully attractive. When the nuclei finally and definitively emerged as planets the process of assimilation still went on and the nuclear planets continually drew to themselves unattached fragments of the matter from which they had first emerged. Thus as an alternative to the gaseo-molten Earth solidifying and cooled, we have an Earth which "grows up" by the addition of other bodies. Instead of cooling, the primal Earth began by increasing in heat and in size.

This second conception has greatly altered the views which were taken in the last century of the Earth's early development. The image of the primal Earth which was the result of Laplace's theory, pictured it as a small star, a fluid globe with a heavy vaporous blanket which held within its folds the future waters of the globe and heavy gases. Thereafter the fluid globe was believed to have begun to solidfy about its surface. It would have at first a temperature of about 2500 degrees or something below that of red hot iron; and the atmosphere by which it was surrounded would still hold all the waters, all the carbonic acid gas and all the oxygen which have since became shut up in dead or living things. After a time, as the cooling went on, the oceans would form out of the atmosphere; and might either

have covered the whole Earth or have temporarily lodged in some great depression of the globe. In the first or oceanless period, the pressures of the forming rocks would have first begun to operate, partly owing to the action of solidification, partly to the fluctuations of heat. Then in the second period when the oceans were laid down, the action of water, the action of a moving atmosphere, and the accumulation of sediments, would bring new forces into play, and at the end of what might be described as the second era, the Earth's upper crust would have begun to take form.

Objection to the Gaseo-molten Theories

That is the theory, stated in the briefest way, of the development of the Earth from a gaseo-molten body. But simple and plausible as it appears to be, there are objections to it which shake its probability. In the first place, there has never been found any trace of the original crust of the globe. There is no rock to which we can point and say definitely "here is the first rock of the globe, formed out of the molten earth-stuff before life existed, and before the oceans were laid down". In the second place, there are positive reasons for believing that no great enveloping blanket of atmosphere, such as the theory demands, ever existed. These are the general objections. They do not disappear when examined in detail.

The Earth's Primal Crust

If the Earth solidified from a molten state, then the liquid mass might be expected in solidifying to produce a homogeneous crust. If it cooled very slowly the mass might have arranged itself in layers, the lighter rocks uppermost. If the boiling was too vigorous for this then the upper crust or outer zone of rock would still be homogeneous in character because there could not well have been permanent

areas of light rock in one region and of heavier rock in a neighbouring one, owing to the laws of the equilibrium of liquids. In either case we should expect to find, below the sedimentary rocks which have been accumulated since, a universal substratum of ancient lava, such as could always be identified from some definite qualities. We should expect it to be a rock coarsely but completely crystallized; and any subsequent conditions to which it became exposed, either of heat or of pressure, would hardly disguise it beyond recognition. But, it may be urged, could not the original crust be concealed by volcanic ash and fragments heaped on it in those ages? That cannot be accepted as a possibility if we suppose that while the Earth was at this stage of cooling, it was surrounded by the atmosphere which contained the future waters of the globe—for evidently there was no agency present, such as the explosive force of steam, to produce explosions. Many thousands of feet of material have in the course of ages been eroded from the surfaces of the oldest known rock areas. We cannot believe that the quantity of volcanic material was so large — greater in quantity than these thousands of feet—that it has never been cleared away by erosion.

But the most searching criticism of the doctrine comes from recent discoveries. It was thought till the closing decades of last century that the great granite-like areas of the oldest known series of rocks, answered the supposed requirements of the case, and that these ancient igneous rocks might be regarded as the ancient earth crust. But it was proved almost contemporaneously that in no fewer than five of the granitoid regions studied, in Canada, the United States, Great Britain, Scandinavia and Finland, these rocks could not be regarded as a primal crust. Many of the great granite masses are seen to be not of the nature of a cooled crust, but are shown to have been *thrust up* through other rocks formed on the surface by flows of lava, or fragments of volcanic

origin or rocks laid down as sediments. They are in fact *intrusive* rocks; they were heated and active ages after the era in which they should have been dead and cold and quietly laid by as a crust—according to the theory. Not all the most ancient rocks have been examined, and therefore it is not possible to say that all of them are intrusive; but there is a strong presumption that such is the case. This new interpretation reduces to the vanishing point the area of massive crystalline rock which can be considered as the supposed original crust. If the molten globe theory were true we should expect to find, not a small amount, but a very large area of such ancient rock crust; because all the vast series of sedimentary rocks must have been derived from it. Furthermore, it is becoming more and more evident that the original source of all this sedimentary material was the existing great land area.

It used to be thought that great reversals of land and oceanic areas had taken place; it is becoming every day clearer that despite oscillatory movements of the oceans towards the poles, and despite many great and small encroachments of the sea on the land, the ground plan of the great land masses and of the oceanic depths has always been roughly the same.

Among the strata of the continents there is none which shows evidence of having been a *deep* sea deposit; the deposits which are known to be laid down in ocean depths are not found in continental rocks. There is nothing to lead us to suppose that the continents were pushed up to great heights out of the oceans from time to time and kept there till wind and water had scraped from them the materials for stratified rocks; and then were lowered to ocean depths again. Minor encroachments may have taken place; but there remain great areas which have perhaps never been under water at all; and other areas which have never received from the sea anything approaching the amount of

material they have yielded to it—the material swept from it. Therefore unless we are supposing that the original land areas of the globe, those in existence when the crust was formed, have received accessions from some other source than the sea, we should expect to find some of them still at the surface; and others of them buried so lightly under sedimentary rocks that they would be accessible. If we find *no trace* of original molten crust—then we shall have no reasonable support from actual observation that there ever was such a crust.

The Earth's Primal Gases

The second difficulty arises from the assumption which goes with the gaseo-molten theory that the atmosphere and the hydrosphere were excluded from the molten globe and surrounded it as an envelope. The idea was that since heat expels gases from liquids and solids, therefore the separation of the gases from the white hot rock of the primitive molten globe should certainly have been complete. Under this view absorption of the gases, rather than their expulsion, should have been the rule in all the later and cooler states of the Earth. Thus when the molten crust has cooled to solidity the theorists are still left with their enormous warm atmosphere rich in water vapour and heavy with gases like carbon dioxide. But the conditions of the Earth which may be supposed to have followed from it, both in respect of climate and of the support afforded to life, will not accord well with the ascertained facts concerning the Earth's early geologic history which are now coming to light. The atmospheric theory in its original form receives very uncertain support from the ascertained facts.

An attempt has been made to amend it by assuming that lavas however hot may hold large quantities of gaseous constituents. We know that existing lavas bring to the surface great quantities of absorbed gases; and though

the subject of the absorption of gases by molten rock is at present imperfectly mastered, it is not impossible to suppose that a great molten globe of rock which has arrived at a liquid state from a previous stage when the rocks were all vapourized, might yet retain large quantities of the atmospheric gases while it was still liquid. We may go still further and say that a good deal of the atmosphere might remain shut up in the solid rock, even after it had become solid. Allowing these things, it may be held that during the Earth's molten period some of the gases remained in the rocks, not fully separated from them, and that there was an unknown state of equilibrium betwen these gases and those in the outer atmosphere. When the rocks cooled to solidity a readjustment of this equilibrium would take place.

The formation of the crust would be followed by a period of great volcanic activity. That might be expected from the readjustment of the gases of the lithosphere (or molten rock), of the hydrosphere (or water-forming gases), and of the atmosphere. In such circumstances the early volcanic era can be supposed to have been so long continued and so violent that the primitive Earth crust was deeply buried under the material hurled out by the great primitive volcanoes. It became so deeply buried in fact that it has never been exposed since. On the same hypothesis we may suppose that the bulk of the sedimentary rocks have arisen from the material furnished in this great volcanic age. Some of the material may be supposed to have constituted enormous lava flows (such as can be seen on the Moon); other portions of it were built into strata made up of fragments of primal rock. As the volcanic rocks were built up they were continually subject to disturbance and to the intrusion of new masses of igneous rock. When the temperature of the world at its surface had fallen below the boiling-point of water, the water vapour of the atmosphere condensed in rain, and water came on the scene to mingle with the lava,

to promote new explosions and to give rise to the sedimentary rocks. These suppositions, especially if the primitive volcanic era can be imagined as extremely extensive, violent and long continued, will account fairly well for the features of the earliest known rocks. It still leaves the early world with too vast an atmosphere: and by the later American geologists, and notably by Chamberlin and Salisbury, the theory is not thought to be adequate.[1]

THE PLANETISMAL HYPOTHESIS

These writers are chiefly responsible for the alternative theory of the planetismal hypothesis, which supposes that the Earth having begun as a knot in the spiral nebula grew gradually to its present mass by additions from outside. The chief point in which this theory differs from the others is that the original nebular knot constituted only a small fraction of the grown planet. If it was quite small then its constituents would have had to be heavy. Its material would have had to be of high molecular weight because light molecules, which have great velocities, would escape. But originally the nucleus is supposed to have been a number of small fragments—planetismals—which had become collected in a group and kept there in consequence of their mutual attractions for one another. This group of fragments would have become gradually welded together into a solid mass as it captured more and more wandering planetismals, or fragments, which passed near its orbit. If anyone will stir the tea in a cup and watch how the wandering bubbles collect in a larger aggregate he will have a picture of the process. The planetismals were chiefly solid bodies, and when they came into collision they destroyed each other's orbital motion, so that they tended to fall towards a common centre.

[1] "Geology," Vol. II, "Earth History," p. 190, by T. C. Chamberlin and R. D. Salisbury (John Murray).

Attraction and Retention of an Atmosphere

During its early career the solid nucleus may not have been massive enough to wrap a gaseous atmosphere about itself. It is not at present quite certain how large a planet must be in order to hold an appreciable atmosphere permanently; but it seems probable that when the young Earth was about one-tenth of its present size, and had a radius rather over 2000 miles, it had an atmosphere, though a slight one. There were two sources whence its atmosphere could have been derived. We have begun by supposing that all the matter of which the parent nebula was composed, all its atmospheric and water-making material, which was not gathered together into the planetary nuclei, remained as free moving molecules or fragments. Dr. T. J. See,[1] who has enlarged the spiral nebula theory of the origin of the solar system by supposing that the spiral may represent the meeting of two streams of cosmic dust instead of the meeting of two suns has further pointed out the probability that some form of gaseous material, or at any rate some material dense enough to resist motion, would fill the whole domain of the spiral. Now the planetary nucleus moving through this could not at first gather and hold the lighter molecules even when they came into collision with it. But as it grew heavier and larger by picking up more and more planetismal fragments such as it could hold, it would be able more and more effectively to retain the atmospheric molecules it met and to add them to itself as an atmospheric envelope. While the nebular state of the solar system continued there would be a much more abundant supply of this sort of atmospheric material than afterwards. But the source of supply may be supposed to continue to the present day: because if gas molecules can fly off a

[1] "On the Cause of the Remarkable Circularity of the Orbits of the Planets and Satellites," by T. J. See, "Astr. Nach." February, 1909.

planet, or a planetismal, or any smaller body, into space, then they must remain in space subject to capture by bodies large enough to take them and keep them.

The fragments of solid matter which the growing Earth was adding to its bulk also contained, shut up within them, gases which might be partially released on collision, or which might remain shut up for some time. The meteoritic stones which still strike the Earth in considerable numbers contain on the average several times their volume of condensed gas. So do most of the igneous rocks of the Earth, and though these gases are very securely held and slowly given up, still they are given up. The case of the gases shut up in meteorites is very instructive from this point of view, for these bodies have traversed depths of gas-less space, and have survived unknown vicissitudes of heat and shock, and yet have kept gases within themselves. They repeat in miniature the earliest history of the Earth. What the kind of atmosphere was which the early Earth held we can arrive at chiefly by examining the gases shut up in meteorites and in the crystalline rocks. We may speculate also that when the proper time arrived the Earth might pick up and retain any gaseous material which had been cast into the nebula from the ancestral Sun and had been able to remain free there. Further consideration may presently be given to the constitution of the primitive atmosphere. For the moment it will suffice to say that its probable constituents were, in order, carbon oxides, oxygen, nitrogen, water vapour, and hydrogen.

It is more important to consider immediately how the atmosphere was fed by the rocks of which the Earth was built. The gradual decay of rocks would furnish the Earth slowly and continuously with contributions to an atmosphere ; though, as far as observation goes, the contributions thus received would be of no great importance. This, however, is not the view held by Dr. Suess, the most eminent of

the German geologists, who rates this process of supply highly; and the geologists who are inquiring into the radio-active emanations of minerals have of late ascribed considerable importance to these emanations, not only as contributions to the atmosphere, but as originating causes of Earth heat.

Apart from these considerations it is well known, however, that vast quantities of gas are shot forth by volcanoes, or exhale more gently from lavas; this is the most obvious way in which internal gases are given forth. According to many geologists it is by no means certain that these are solely internal gases coming for the first time to the surface. They may certainly be the part product of water which has percolated from the Earth's surface. But some at any rate may be justly supposed to be the products of the rocks, in which they have been shut up as chemical combinations, and from which they emerge when these chemical combinations are broken up. If we suppose that the growing Earth contained abundant atmospheric materials, we have then to consider whether enough heat was developed in the growing Earth to set up volcanic action and force the gases to the surface.

Heat of the First Nucleus

If all the fragments which made up the nucleus of the Earth had come together at the same time, the shock of their collision would have been enough to melt the whole mass. But if the collisions were spread over a long period of time, and if the heat caused by the infall of a planetismal fragment were generated only at the surface, where it would readily radiate into space, then the nucleus as a whole might not become very highly heated. There might not be enough internal heat to set up volcanic action. It may, perhaps, fairly be assumed, however, that in the Earth's early history it was gathering up planetismal additions often enough to

keep it red hot; and it was only later when the fragments in its path were thinned out that its surface became cool. Suppose, however, that there were not enough collisions to keep it hot—had the young Earth any other supporting sources of heat? An unknown amount of heat may have been bequeathed to it from the parent nebula out of which it was born as a nebular knot. This knot was presumably an aggregation of heavy molecules of the nebular material, chiefly the molecules of metals and rocks. We adopt that supposition because these elements could become liquid or solid even while the temperature was high (which the lighter elements could not do); also because these heavy molecules would be better able to cling together. The conditions of condensation of these molecules might develop a high internal temperature, as the molecules fell inwards. The young Earth may, therefore, have inherited a hot nucleus.

As, however, the earth grew, and while it was receiving additional material, it must have condensed more and more; and as it condensed its internal heat would increase. It is probable that in a body of one-tenth of the Earth's mass enough heat would arise from condensation to melt rock. There would be an additional amount of heat arising from the rearrangement of the atoms and the molecules of the constituent fragments of the Earth after they had become entrapped. Under this head we may for the moment include the heat arising from radio-active action.

Volcanic Action of a Growing Nucleus

This theory, therefore, of an Earth which grew slowly outwards by additions from outside still gives enough internal heat to the Earth to furnish the furnaces of vulcanism. It becomes necessary to consider how this internal heat could have made its way outwards and have so distributed itself as to cause volcanic action. In the first place, the material of which the Earth was composed was of various kinds. Some

years ago Sir William Roberts Austen showed to an audience at the Royal Institution, steel which ran like thick treacle under hydraulic pressure. Perhaps not all the rocks can be brought to the melting-point by pressure alone; some certainly can be. But evidently in the mixture of rocks of different melting-points, there would be local spots where there were masses of rock in the molten state. As the rise of temperature in the whole mass continued, these spots would grow, and other more resistant rock material would grow treacly and plastic like the steel we have instanced. Add to this the tidal movements of the mass, and enough differences of stress would be produced to press these fused spots of rock outwards. As these viscid bubbles slowly pressed upwards through the semi-solid globe, they may have united, forming threads or stringlets of bubbles, which insinuated themselves like tongues through the harder rocks. As these liquid tongues rose higher to levels where the pressure was not so great, and where rocks melted more easily, they carried with them more heat than was sufficient to keep themselves in a molten condition, and then began to melt their way upwards as a red hot poker bores through wood. The tongues lost heat by coming into contact with rocks of low temperature and thus were obliged to leave behind, here and there, rock material that cooled quickly; while at the same time they occasionally took up more fusible material which they met on their way. Among the more fusible or soluble rocks the ascending tongues would certainly pick up a large quantity of included gases with which they would become densely charged.

These tongues need not all reach the surface. They should simply continue to rise until their working capital of heat was exhausted, when they would return to the solid state and remain tongues of intrusive rock. But they would always contribute heat to the regions they invaded, and thus while the internal heat would continually be led by them to

the surface, every tongue which failed to reach the top would, by heating the way, prepare for the greater success of other tongues which followed it. Thus to sum up: the early Earth was always growing by additions from outside; its internal self-compression was increasing along with its growth, and so therefore was its internal heat; and this heat, highest at the centre, was always being carried outwards by the tongues of flowing rock. The outer part of the young Earth was made up of the planetismal fragments which had not yet been melted by pressure (or by the action of air and water) into a solid mass. This porous outer crust of fragments must have extended to a considerable depth while the Earth remained small. When the uprising lava tongues reached this zone they made their way through it without much difficulty. They insinuated their path among the fragments in volcanic dikes and ledges; and may frequently have blasted a way to the surface by the pressure of the gases which they had carried upwards with them. It is possible that at one time the Earth, like the Moon, exhibited pits and craters, through which the lava welled or sometimes burst in bubbles. If we may draw inferences from the Moon's surface, where volcanic action was apparently extremely vigorous, we may conclude that considerable quantities of gases were blown out of the Earth's surface before the Earth was big enough to hold them. The supply was ample.

The Hydrosphere

Both by those who hold the gaseo-molten theory, and those who hold the planetismal or accretionary hypothesis, the original form of the water vapour which formed the Earth's oceans, is called the hydrosphere. According to Chamberlin and Salisbury, the condensation of the globe's water vapour would probably have occurred among the cooled fragmentary rock stuff of the surface before condensa-

tion took place in the atmosphere outside. In other words, the Earth's waters were born underground, and while the outer zone of the Earth remained fragmental, formed a layer of water or hydrosphere below the surface of the globe. As the water increased in volume it rose to the surface, and presumably first appeared in the innumerable pits of the old craters, or in the other depressions formed by the settlement of the Earth's crust. Thence from innumerable lakelets it grew to rivers, to seas, and to oceans.

Such is the planetismal hypothesis; and its plausible simplicity is such that no account of the growth of a planet either in the early or the subsequent stages is complete without continued reference to its principles. None the less, it is necessary to consider the conditions of heat and pressure at the Earth's interior, as reflected by the older hypotheses, because whatever may be the truth about the early stages of the Earth's growth, some of the most valuable observed facts of geology have been co-ordinated on the assumption that these older hypotheses are correct.

PART II. THE OLDER HYPOTHESES OF A COOLING EARTH

There have been two ways of regarding the cooling process of a planet which solidified from a sphere of incandescent gas and molten material. According to the first view when the temperature of the sphere had fallen low enough a crust began to form on its surface. Solidification began thus at the surface. According to the second view solidification began at the centre, because although the temperature there was highest, the pressure there was also greatest. Thence solidification would proceed outwards.

The first view may be taken first because most of the discussions concerning the internal heat of the Earth have been founded on it. Before the crust began to form the distribution of heat in the perpetually stirring liquid mass should

have become roughly uniform, so that the temperature at the centre and at the surface were nearly the same; and this temperature was assumed by Lord Kelvin to have been about 7000° F. As cooling continued the loss of heat would be felt at first only in the outer shell; and it would gradually spread in successive eras towards the lower depths. In 100,000,000 years the cooling effect would spread to about 160 miles below the surface. In 237,000,000 years depths of 240 miles would be affected; and even after a lapse of 600,000,000 years the original temperature of the core of the Earth would remain much the same as at the beginning. At about 300 miles from the surface it would be unaffected by the flight of time or the loss of heat. This theory has a special interest because it was long held to be the most promising explanation of the wrinkling of the Earth's crust. The extreme outer crust or shell after cooling would remain naturally unaltered in dimensions; but all the time the inner crust or zone, which was supposed to be always cooling, would continue to contract. Below 160 miles there would be no contraction; the state of things remaining the same there for 100,000,000 years. But between these two levels there would be great contraction, great changes of dimension and the greatest alteration would be taking place at about sixty miles below the surface. The contraction of this middle zone, while the outermost shell and the inner core remained unchanged, would have produced "horizontal thrusts" in the outer shell because when it became too large for the shrinking crust underneath, it would begin to settle. The familiar illustration of the wrinkles on the ancient apple will be present to all minds.

The Level of "No Stress"

We shall have then an outer shell which is too large: its too great size makes it crowd in on itself horizontally. Below it will be a zone where on the contrary there is a

state of shrinkage. "Between these two opposites there must be a *level of no stress* where there is neither compression nor stretching."[1] Above this level the thrust increases towards the surface; below it the stretching increases till the level of no change of temperature is reached, when it ceases. When the Earth first began to cool the "level of no stress" must have been near the surface and have gradually sunk lower. Varied computations of the thickness of the outer crust or shell where these horizontal stresses ought to take place have been made. The Rev. Osmund Fisher[2] estimated the depth at less than thirty miles. The extreme computation places the thickness of this straining shell at between eight and ten miles.

Solidification from the Centre

Let us now consider the second view, which imagines that the molten Earth first solidifies at its centre. When the idea of an Earth which cooled first at its crust was discussed not very much was known about the melting of rocks. Pressure makes a very great difference in the height of their melting-points. At a temperature of 8000° F. and at the ordinary atmospheric pressures at the Earth's surface there is no known solid that would not melt and change into a gas. But when bodies are subjected to very great pressures they can sustain much higher temperatures than heretofore before changing from a solid into a liquid, or from a liquid into a gas. A little consideration will show that this must be so. All substances might be regarded as having three states, solid, liquid, gaseous. For convenience zero temperature

[1] Chamberlin and Salisbury, "Geology," Vol. I, p. 535.

[2] "Physics of the Earth's Crust" (2nd edition, 1889), pp. 22, 41, 54, 178. Mr. Fisher thinks that the available evidence points to the existence of a crust which may have an average thickness of 25 to 30 miles: and that beneath it lies a substratum of fused rock possibly saturated with water-gas far above the critical temperature. The substratum he regards as being traversed by convection currents, and as being not merely viscous but actually liquid and melting off portions of the crust above it from time to time.

(except on the Fahrenheit scale) is generally taken as being the point at which solid ice begins to melt into liquid water; but this is a quite arbitrary constant. Absolute zero, the lowest point of temperature which can be reached, has been calculated by Lord Kelvin at $-273°$ C. below the melting-point of ice. Absolute zero is the point at which all known substances would be in the solid state. Taking this as a starting-point we can assign positive temperatures to the melting-points and volatilizing points of all solids, liquids, and gases.

Thus air liquefies at $-193°$ C. ordinary scale.

On the absolute scale air is solid at about $+80°$; becomes liquid somewhere between $+80°$ and $+91°$ and volatilizes or turns into a gas at about $+92°$.

Similarly water is a solid at $+273$ degrees on the absolute scale, it becomes a liquid after $+274°$ has been reached. It begins to boil into a gas at $+373$ "degrees absolute" or $100°$ C.

Similarly also lead is a solid at $+273$ "degrees absolute" and remains solid for more than $327°$ after that. Then at 601 "degrees absolute" it melts into a liquid. If the temperature is still further raised it volatilizes into a gas.

These temperatures, roughly, are those which are assignable to the melting or solidifying points of air, water, or lead when the ordinary atmospheric pressures are part of the conditions. But as everybody knows, the boiling-point of water can be altered by taking off pressure from the surface of the liquid. At the top of Mont Blanc water's boiling-point, or the point at which the liquid is changed into a gas, is *lower* than at the sea-level, because the atmospheric pressure is less.[1] If the atmospheric pressure were increased the converse would be the case. One would have to apply more heat to the water before it would begin to change from liquid into gas. Similarly

[1] See also Chapter XI.

the normal changing point of any substance can be raised by applying pressure to it; and if we are dealing with solid rock, then if we apply sufficient pressure to it, we can theoretically apply the highest experimentally attainable temperatures to it without inducing it to "change its state" from the solid form into liquid.

MELTING POINTS OF ROCKS UNDER PRESSURE

It has been shown experimentally that the melting-point of a quartz-like rock (such as diabase) grows proportionally higher as pressure is applied; and theoretically such a rock if subjected to pressures equal to those which would be experienced at the centre of the Earth, would not melt at a lower temperature than 76,000° C. or 136,000° F. This can only be regarded as a speculative result, because under the unknown and uncomprehended conditions of the Earth's core, the rate of change of a rock's melting-point would probably be altogether different from that which we can surmise from experimental pressures. But there is, at any rate, reason for believing that solidification in the Earth's interior would prevail in spite of very high temperature because of the great pressure. The pressure at the centre of the Earth has been calculated as equivalent to 3,000,000 times the pressure of the atmosphere at the Earth's surface; or 45,000,000 lb. to the square inch.

Under this theory the pressure about half-way down would be rather more than a million and a half atmospheres to the square inch and the temperature about 40,000° C. The view taken of an Earth constructed on these principles is one in which when the temperature of the gaseo-molten globe sank low enough at the centre, solidification of the melted rock set in there; and that similar solidification took place at lesser depths in succession as the appropriate and still lower temperatures were reached there. A most important consequence of this view, if it were the true one,

would be that cooling and shrinkage would affect the deep interior of the Earth, for the high central heat is supposed to have continually travelled outwards to the surface. Therefore instead of a shrinking contracting zone of some 200 miles in depth, we should have a belt of cooling and shrinkage perhaps 2000 miles or more in thickness.

Part III. Distribution of Heat

Let us now return to the theoretic distribution of heat in the Earth's interior under the assumption that the Earth grew by the continual addition of planetismals to its central core. The heat in this case would rise as the increasing number of additions to it caused compression at the centre. As long as compression continued the heat would continue to rise at the centre—as long as the heat which was generated by compression was greater than was lost by travelling outwards to the surface. Heat travels very slowly through rock, so we may assume that the central heat continued to rise so long as the infall of matter caused compressions. The less central parts would also be made hot, if less hot, from similar causes of compression, and would also be warmed by heat conducted to them from the centre. A mathematical consideration of these two processes shows that the temperature would gradually fall in the deeper portions of the Earth and would rise in the outer ones. (It would not, however, rise in the outermost crust because this is subjected to outside cooling, arising from radiation of the heat into space). Leaving out of consideration this outermost crust or surface, there would be a depth of about 800 miles where the temperature was rising. Below these depths the temperature would be falling. But in the rising temperature zone there would be an expansion of rock due to the rising heat. Below that there would be a shrinkage of rock owing to falling heat. The upper zone, already forced to con-

form to the shrinking cooling core, would find the task more difficult owing to its own expansion. There would consequently be an imaginable state of affairs in which a continual redistribution of heat was taking place, and in which melting rocks were continually being forced up into higher levels. Thus we begin to imagine an Earth in which shrinkage and deformation of the rocks need not begin merely towards the surface, but may originate at deeper levels.

By comparing the three hypotheses of the early states of the Earth, it will be seen that the last two differ altogether from the first. The first assumes that the interior of the Earth slowly and evenly declines in temperature from the centre outwards. The second and third ask us to imagine that there are great alternations and differences in temperature deep down in the Earth; and that the re-distribution of temperatures gives rise to great deep-seated strains and stresses. If the stresses are only at the surface they would be readjusted quickly. If deep seated they might accumulate for long periods and give rise to far more conspicuous results at long intervals of time. Stresses of the first kind might move mountains; but the deep-seated long-delayed action of the second kind might stir continents.

Underground Temperatures

It is rather humiliating by the side of these speculations to set the actual knowledge we have attained of Earth temperatures and Earth depths. The deepest boring known is that sunk by the Austrian Government at Paruschowitz in Silesia; and it attains a depth of 6408 feet—considerably less than a mile and a half. Its diameter is $12\frac{1}{2}$ inches at the surface, and about $2\frac{1}{3}$ inches at the bottom of the boring; and the engineers in charge of the experiment stated that they could not have reached this depth had not Mannessmann weldless steel tubes been available for the boring rods. The Hon. Charles Parsons made a calculation some

years ago of the estimated cost in time and money of a deep shaft, in the recesses of which some of the problems of Earth structure might be solved for us. For £5,000,000 a bore hole twelve miles deep could be drilled; and it would take some eighty-five years to construct.

Not less disconcerting than the positive ignorance of underground depths are the conflicting inferences to be drawn from underground temperatures. The temperature increases with depth, so that at the twelve mile level of Mr. Parsons the heat should certainly be enough to keep water always boiling. But there are the most widely differing estimates of the rate of increase.[1] Lord Kelvin in his earlier estimates adopted a rise of 1° F. for every 51 feet of descent. A Committee of the British Association appointed to consider the question of underground temperatures arrived at an average value of 1° F. for every 60 feet of descent; and Prof. W. J. Sollas suggests that a re-investigation of recorded measurements would lead to a rate of 1° F. in 80 or 90 feet as more closely approaching the mean. In the British Isles alone the rate varies from 1° F. in 34 feet to 1° F. in 92 feet or in one case to 1° F. in 130 feet.[2] Prof. Sollas[3] remarks that while these irregularities have in some instances been referred to differences in conductivity of the rocks, and in others to the presence of underground water, yet there are many cases which cannot be explained away in such a manner, and which are suggestive of some deep-seated cause, such as the distribution of molten matter below the ground.

Radio-active Production of Heat

During the last few years a new factor in underground heating has suggested itself to geologists and has received

[1] See also Chapter XI.

[2] In the Calumet and Hecla Mine, Lake Superior, which is 4989 feet in depth the rate varies from 1° F. in 103 feet to 1° F. in 93 feet.

[3] British Association, Section C, 1900.

special attention from Prof. Joly of Dublin.[1] This is the possible influence of radio-activity on underground temperatures. Radium, which we select as the most representative of the radio-active minerals, is continually giving out heat owing to the disintegration of its atoms. The amount of heat which a gramme of radium would give out in its lifetime (that is to say before it was entirely disintegrated) seems to be enough to raise 100 tons of water through 1° C. That is probably an underestimate. The amount of heat generated may be a hundred times as great as that. Radium is one only of many radio-active minerals, and the researches of Mr. Boltwood[2] seem to establish positively the fact that it is the product of another more plentiful mineral, uranium, which may be said to stand in the relation of grandparent to its spendthrift descendant. The supply of uranium near the surface of the Earth is surprisingly large. Radium is itself a very widely distributed surface material and has been found in all the depths at which we have been able to penetrate; in underground springs, in volcanic muds, and in the sea. It has been found in meteorites. Its presence is inferred with some degree of probability in the Sun, and is distributed throughout the material of which the Earth was built.

Unless we are to suppose therefore that radio-activity is a phenomenon of modern geologic time, we have to consider our globe as made up of matter through which was distributed in some quanity or other, elements which by their atomic disintegration, were and are imparting heat to it. It is unlikely that radio-active rocks are entirely absent from the Earth's core. If they are there present, these parts may be growing hotter from the heat given out by by this

[1] "Radioactivity and Geology: An Account of the Influence of Radioactive Energy on Terrestrial History," by J. Joly (Constable), 1909.

[2] "On the Life of Radium," by Bertram B. Boltwood, pp. 493-505, "The American Journal of Science," Vol. XXV, June, 1908.

source. That is one point which Prof. Joly makes. Another is a particular effect of this heat. The heat will be greater in some areas than in others; and will be especially great in surface areas, where great thicknesses of sediment have been deposited.

In such surface areas there will be a great expansion of rock due to the emanation of heat, and this will powerfully affect mountain building. But evidently similar release of heat, or differences in the rate of release of heat, will create differential temperatures throughout great zones of the Earth's crust. "We have," says Prof. Joly,[1] "in these effects an intervention of radium in the dynamics of the Earth's crust which must have influenced the entire history of our globe, and which affords a key to the instability of the crust".

It will be seen, that while the earlier theories to account for the condition and history of the Earth's interior assign the distribution of heat therein to causes which have followed from the conditions of heat and matter that were present when the world began, they derive the energy which has been responsible for the present structure of the crust, from the residuum of the original heat; or from compression; or from the collisions of planetismals. But the new theories of the heat evoked by the breaking down of atoms invite us to consider the existence within the Earth of a vast store of energy which is chemical in origin, and which arises from the decay of the elements; and not from the alteration of their molecules alone but from the decay of their atoms. It has indeed been contended that all the heat which has been observed in mines, tunnels, and borings, is of an order which could be accounted for in this way.

Review of the Theories

Having presented in the foregoing chapter some of the views entertained concerning the temperature and conditions

[1] "British Association, Presidential Address to Geological Section," 1908.

of the Earth's interior, a few words may be added by way of a summary and perhaps also by way of warning. "We know practically nothing," remarks Dr. C. G. Knott,[1] "of the properties of matter under the enormous pressures which certainly exist, and the high pressures which presumably exist in the nucleus of the Earth." The theories rest on foundations not of observation, because in the more direct sense observation is impossible, but on assumptions which have been chosen because they are amenable to mathematical treatment. This criticism applies to every theory from that of Laplace to that of Kelvin, and from that of the Rev. Osmund Fisher to those of Sir G. H. Darwin and Prof. Simon Newcomb.

Newcomb has made a computation of the rigidity of the Earth and of its various parts. Its rigidity on a whole he computes as comparable to that of armour-plate steel.[2] At the Earth centre the rigidity under pressure rapidly increases and in spite of the high temperature presumed to exist there this rigidity is probably three times as great as that of hardened steel. The rigidity of the crust he estimates as not greater than that of granite, and only one-sixth that of steel.

[1] "The Physics of Earthquake Phenomena," by C. G. Knott, p. 272 (Clarendon Press), 1908.

In a letter in "The Times," 5 August, 1906, Lord Kelvin wrote from Aix-les-Bains: "To raise a warning against hasty generalization as to the transmutation of elements which had been suggested at the meeting at York as a deduction from the discovery by Sir W. Ramsay and Prof. Soddy of the production of helium from radium". He also protested against the hypothesis that the heat of the Sun or of the Earth is due to radium; he held that it is mainly due to gravitation. To this Sir Oliver Lodge replied, regretting that physicists had been unable to carry their veteran leader with them in some recent developments. . . . Lord Kelvin in "The Times" of 20 August, ". . . contended that there was no valid experimental evidence to show that the heat of radium was sufficient to account for sun-heat or underground temperature" ("Life of Lord Kelvin," by Silvanus Thompson, Vol. II, p. 1190 (Macmillan), 1910).

[2] "Monthly Notices, Astron. Soc." 1892, p. 336. Rudski of Odessa makes the rigidity twice as great as that of steel ("Phil. Mag." 38 (1894), p. 218).

As a mathematical proposition, that statement may be said to hold its own. But with regard to the interior conditions of this rigid globe the theories are in conflict as to terms. Lord Kelvin to his death never abandoned his concept that the Earth was to be regarded as a rigid solid globe. The Rev. Osmund Fisher, his contemporary and his survivor, has never withdrawn from his theory that under pressure the core of the globe remained solid and was surrounded by a fluid substratum, which, however, under pressure, remained immovable though viscous. Prof. Arrhenius,[1] of Stockholm, arguing that at the temperatures which exist at the centre of the Earth all matter would turn into gas, believes that the larger portion of the Earth's core is gaseous; that it then passes into a liquid layer, and that the liquid layer finally merges into a solid crust. Both in the conceptions of Arrhenius and of Fisher it must, however, be assumed that the pressure is such that both liquid and gas under its influence behave as rigid bodies. In an unscientific phrase the gas and the liquid are as *hard* as if they were solid. Finally, in Chamberlin's view the whole globe is solid in

[1] "Zur Physik des Vulcanismus" ("Geol. Foren. Stockholm," Forhandl. XXII. (1900), pp. 395, 419. See also for summary of Arrhenius' theory, Geikie's "Text Book of Geology," 4th edn., 1903, Vol. I, pp. 72, 73). "When," says Arrhenius; "we speak of gases at such high temperatures and pressures as those, that prevail in the Earth's interior, we must conceive of something wholly different from what we ordinarily understand as gas. The density, compressibility, and viscosity of such a substance are of such a high order that we might regard it as a solid body, if its true nature were not apparent. . . . At a depth of about 25 miles, where the temperature reaches as much as 1200 C. and the pressure amounts to 10,840 atmospheres, most ordinary minerals will become fluid and the Earth's substance must at that depth exist in a molten condition—a molten magma. This condition must, however, extend far inward. For at 186 miles the temperature is so high as to be beyond the critical temperature of every known substance. The liquid magma then passes continously into a gaseous condition. . . . The interior of the Earth, therefore, with the exception of a solid crust about 25 miles thick, consists of a molten magma 70 or 150 miles in depth which shades continously into a gaseous centre. The liquids and gases in the interior possess a viscosity and incompressibility such as permit them to be regarded as solid bodies."

effect, but it has liquid tongues starting from the middle zone, and working their way outward.

Seismological Contributions to the Theories

Lord Justice Fletcher Moulton, in some evidence before a Royal Commission, once said that the right way to advance science was by experiment. Where we are reduced to observation science crawls. He adduced the knowledge of the causes of volcanoes as one which was extremely limited because no experiment was possible. The same considerations apply to our knowledge of the Earth's interior, where we are confronted, moreover, by the absence of opportunities for investigation. But in a sense, the Earth itself makes experiments for mankind. It does so in the instance of earthquakes ; and it is possible that the continued observations of these tremors of the rigid body may in the future offer a clue to the globe's inner constitution. When an earthquake occurs its vibrations pass along the Earth's crust to distances of several thousand miles. These vibrations or tremors do not travel all at the same speed ; and do not travel all in the same way or through the same portions of the Earth's crust. The large waves pass along the curved outer crust, as a tremor might travel along the rind of an orange. Other tremors appear to take a shorter cut, cutting through the pulp of the orange. The big waves travel along arcs, the small tremors along chords. But there are two kinds of small tremors which travel at different speeds. Mr. Oldham,[1] in a paper read before the Geological society (1906), advanced the theory that these two kinds of "preliminary earthquake tremors" represent the emergences of two distinct forms of wave motion which have been propagated through the Earth from the origin of the disturbance. Both these forms of wave motion arrive late at the

[1] "Geological Society Quarterly Journal," 1906.

distant seismological observatories of the world. In the first preliminary tremors the speed at which they have travelled is nine-tenths of what it would be if they had travelled along the outer shell or crust. In the second tremor the speed is only one half of what it should be. The great reduction of the rate of travel in the "second tremor" waves appears to show that there has been great refraction or bending of the waves at some point in their journey. Mr. Oldham's theory was that before the waves reach the distant observatories they have impinged on a central core of the Earth which is of different rigidity and physical conditions from that of the other zones. His conclusions are criticized both by the Japanese seismologists and less severely by Dr. C. G. Knott, who believes that the number of observations of this kind yet made are too few in number and too fragile in other respects to warrant so great a superstructure of theory. But we may quote the conclusion at which Mr. Oldham arrived from the consideration of earthquake tremors. He was led to suppose that below the outermost thin crust of the Earth there existed matter which was homogeneous in material and physical condition to a depth of about 4500 miles. Below that he believes there was a rapid passage to matter which differed from it greatly in rigidity, density, and in other physical attributes.

CHAPTER VI

THE SHAPE OF THE SOLID EARTH

The interior movements of large solid bodies—Land and water distribution on a planetary orb—Changes caused by rotation—The shape of the Earth—Spherical harmonics—Mathematical distributions of land and sea—Distribution by rotation—Combined effects of rotation, lopsidedness, and deformation—Theory and observation compared—The periods of alteration of shape—Evidences of change.

AS a corollary to the speculation that the Earth and the Moon were once one planet, it has been urged that in the Earth's shape there remains a testimony to their severed unity ; and that the basin of the Pacific Ocean suggests itself as the scar left by the severance. Some reasons for regarding the suggestion as fanciful have already been stated. To them may be added another which is that simpler explanations of the Earth's shape have arisen from the mathematical investigations of Sir G. H. Darwin, Prof. Jeans, and Prof. Love.

Interior Movements of Large Solid Bodies

It is not necessary to suppose that the Earth took final shape at a period when it is to be regarded as a spinning mass of liquid, or as a body partly solid, partly liquid. There are laws governing the shapes of planets. In such plastic bodies the persistent dominating force is that of gravity. There is a tendency on the part of all the grains or particles which constitute the bulk of the body to fall inwards. A planet is, in short, a gravitating body. But sup-

pose that all the parts of such a gravitating body are not equal in density. Evidently the denser parts will attract particles to themselves more strongly than parts which are not so dense. Evidently also more and more of the particles of the mass will tend to be drawn towards the denser parts. So that in every system of particles which exists on a basis of gravity there is a tendency to change. If the system is as big as a planet there will be a concentration of the mass towards the centre, or towards some other point which is not the centre if the densities are unevenly placed. But there is a check to movement and concentration. Concentration such as we have imagined must be accompanied by compression, and there is a limit to compression. The material refuses to be compressed any further. Thus there is a kind of competition between the two forces—the gravitation which is accompanied by movement; and the elastic resistance to compression which arrests it.

Gravitation, in Professor Love's words, makes for instability; the elastic resistance to compression makes for stability. There are instances of these competing agencies more familiar to us than those which the planets furnish. A long thin bar set up on end will tend to bend under its own weight. A knitting-needle a foot long will stand up; a shaving of paper of the same length will bend over. Apply the same order of ideas to the case of any body; and it will be seen that in order to keep its shape there must be some relation between the forces which tend to induce a change of shape; its size; and the resistance which the body offers to change of size and shape. When we consider a gravitating planet we ask how small its resistance must be in order that its shape may change; we ask also what kind of displacements would be affected by its tendency to change. If we know the constitution of the planet we have a definite mathematical problem. The greatest difficulty before us in solving the problem for a body of the size of the Earth is to find

equivalents for the enormous stresses which are developed within it by the mutual attraction of its parts. The Earth is in a state which is described technically as a state of "initial stress". So, to take a common example, is the rubber-cored golf ball. The core made of tightly wound elastic, and the thin crust of composite matter that covers it together constitute a sphere which for all its placidity of appearance, is the residence of struggling forces. It is in a state of stress; and according to a high golfing authority its centre of gravity is seldom at the centre of the ball. We will not press the comparison too far; but for different reasons there may exist a dislocation between a planet's centre and its centre of gravity. In both instances the strains tend to disturb the sphere's stability; there is a tendency to "give"; to arrive at readjustments. If the resistance to compression in a planetary sphere is sufficiently small, there will be not only movements towards the centre; but there will be displacements by which the density is increased in one hemisphere and diminished in the other. If the resistance to compression falls low enough; or in other words if the material of which the planet is made is soft enough, then a spherical planet of homogeneous material becomes an impossibility. There could not be a spherical planet of putty. We can imagine a planet of granite in which the material was arranged in thin sheets, nearly spherical; each sheet of the same density. But these shells of granite, arranged like a Chinese ball puzzle, would not have the same centre. They would be crowded together towards one side and spaced out on the opposite side in the manner shown in the figure (Fig. 1, p. 98).

A homogeneous sphere of the same size and mass as the Earth made of a material no more incompressible than granite could not exist. It would be gravitationally unstable. The body would take up some such state of assemblage of its particles as we have illustrated in the diagram;

and its centre of gravity would be some distance away from its centre of figure.

This is the first and most evident way in which a planetary orb would depart in its shape from a perfect sphere. There are other causes of deformation which would come into play, some of which, if not all of which, would become reflected in the distribution of the masses of the surface, or in simpler words in the lie of the land of the planet. In the investigation of which the present chapter is a summary, Prof. Love[1] considered one by one the causes which would deform a planet, and stated the result that such and such a cause would have on the distribution of land and water on a planet. Having taken the causes singly he considered them in combination in an endeavour to arrive at the effect which taken all together they would have on the appearance of a planet. Finally he compared the appearance which by theory a planet like the Earth ought to have, or might have, with the face of the Earth as we know it.

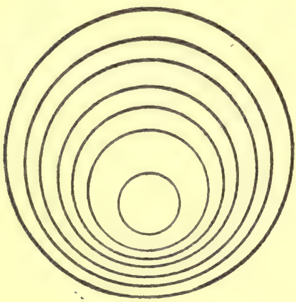


FIG. 1.

Land and Water Distribution on a Planetary Orb

Let us first ask how the waters would rest on a planet which had these two centres—that is to say, a centre of gravity distinct from a centre of figure. Evidently the water surface would be the surface of the sphere which had its centre at the centre of gravity. That would leave the ocean on one side of the planetary sphere. Thus in our

[1] British Association, Leicester, 1907, "Address to the Mathematical and Physical Section on A Dynamical Theory of the Shape of the Earth," by Prof. A. E. H. Love, D.Sc., F.R.S.

imagined planet there would be an hemisphere where land preponderated; and another which was the oceanic hemisphere. Such are the conditions perceptible on the Earth; where there is the great northern hemisphere of continental land and the southern hemisphere chiefly occupied by the Pacific Ocean, directed more towards the centre of gravity than towards the centre of figure.

Changes Caused by Rotation

But we can go much further than this in accounting for the continental and oceanic regions of our planet. What will happen to such a planet as we have in mind when it rotates. A rotating planet, as we have seen, assumes the form of a flattened sphere: but the figure of its ocean, owing to greater mobility, would bulge out more at the equator than the planet itself. Therefore the first effect of the rotation of the Earth on the distribution of land and ocean would be to draw the ocean towards the equator, so as to expose the polar regions. Thus both Arctic and Antarctic became parts of the land platforms.

There is an important secondary effect. In a spinning system of particles the regions of greater density will tend to fly farther from the axis than the regions of less density—as one can imagine if one were swinging about one's head a string on which were corks and bullets; the bullets would tend to move outwards more quickly than the corks. If in our rotating spheroid the density is greater in one half than the other, the effect would be to produce a sort of surface of ridges and furrows.

This analogy can be followed out when we take into account the fact that the Earth is not merely flattened like an orange, but egg shaped. The first effect of this egg-shaped condition would be to raise the land above the water at the ends where the egg was largest. But if there were greater density in one half the egg than in the other half, the

forces of gravitational attraction would produce (to a greater degree than in a spheroid) a greater effect in the parts where the density was excessive. Again, therefore, just as in the case of rotation, there would be a furrowing of the surface.

The problem before the mathematician is, therefore, that of reconciling the features of the Earth as we are able to perceive them with the shape which a solid gravitating planet would assume, and the position which its oceans would occupy on it, if the sphere were of a certain size, weight, and compressibility. We might put the question more concretely by asking what shape a solid spheroid would take if it were 8000 miles in diameter; as heavy and compressible as granite; and if while rotating at a speed of more than a thousand miles an hour it had been subjected to certain distorting forces like the pull of the Moon. Or we might ask whether the observed shape and features of the Earth were such as to fall within any definite and mathematical figure; and if so, whether this figure were what we should expect it to have become from the operations of the primary causes.

The Shape of the Earth

What is the shape of the Earth? If the ocean could be dried up the Earth would still have a shape. What shape would it be? Why should the Earth have that shape rather than some other? In order to describe the shape we may imagine, with Prof. Love, that we try to make a model of it. The model would have to be the size of a Dreadnought if the elevations of the mountains and the depressions of the oceans were to be as much as three or four inches. In thinking out the construction of such a model we should be impressed by certain general features of the distribution of continent and ocean. The tapering of America and Africa towards the south would force itself on our attention; so would the disproportion between the land areas of the

northern and southern hemispheres; or the excess of the oceanic over the continental area (which occupies only about one-fourth of the surface); or the wide extent of the Pacific which together with the adjoining part of the Southern Ocean occupies two-fifths of the surface; or the skew position of South America with regard to North America. But although we may observe prominent features of the distribution of earth and land, we should find it difficult to attribute to the face of the Earth anything which could be called a regular geometrical figure.

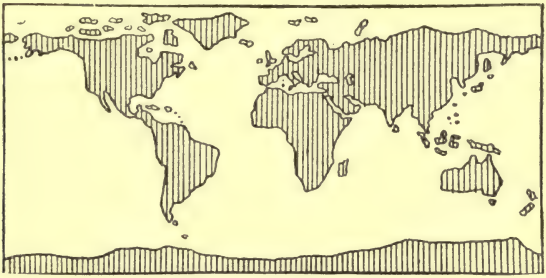


FIG. 2.

If we were making a model of it, then when we arrived at the stage of scooping out the ocean we should require a map giving information about the depth of the sea in different places. Round all the coasts there is a margin of comparatively shallow water. If part of the Earth's oceans disappeared into space, so that the level of the sea fell 1400 fathoms, so much land would then be exposed that its area would be equal to that occupied by the sea. North America would be linked with Asia by the Behring Straits on the one hand and with Europe across the North Atlantic on the other; and the Arctic regions would be part of the same great continent. The Mediterranean would disappear so that Africa would be linked with Europe; while Australia would be joined to Asia through Borneo. South America

would spread out like an inverted mushroom at Cape Horn and would nearly join the Antarctic Continent. (See Fig. 3.) At this depth, therefore, the mathematical problem is simplified. The surface of the Earth is divided into two

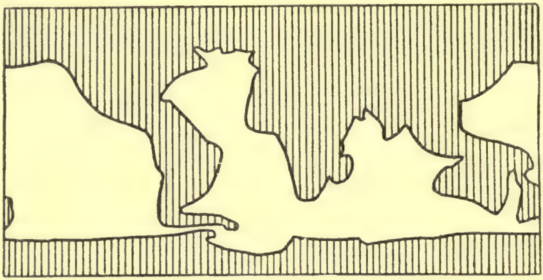


FIG. 3.

regions, one continental, one oceanic, which are approximately equal in area. If we smooth away irregularities we find the surface divided into a continental region which is continuous and into two oceanic regions. One of the

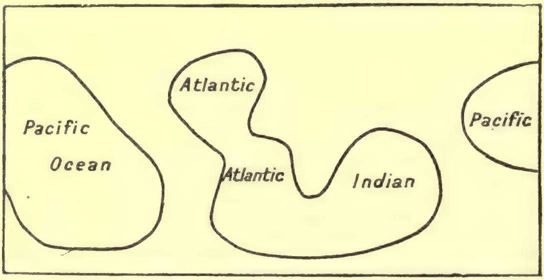


FIG. 4.

oceanic regions is the basin of the Pacific; the other is the combined basin of the Atlantic and Indian oceans. Will a planet existing under the conditions we have named arrange its surface in this way; that is to say, into portions one of which is above the 1400 fathom line, and one below it, and both of which are approximately of this shape?

Spherical Harmonics

Suppose now that a sphere is altered in shape from a sphere. If, for example, it is flattened at its poles and bulges at its equator then some parts of it will have units of elevation (or plus areas); and others units of depression (or minus areas); and there will remain some unaltered areas (or zero areas). These quantities will vary in a regular fashion over the surface of the sphere. Or again, we might remove all the material from the cap at the top of the sphere A and remove it to the south of the dotted sphere B, We should produce a sphere equal to the original but in a

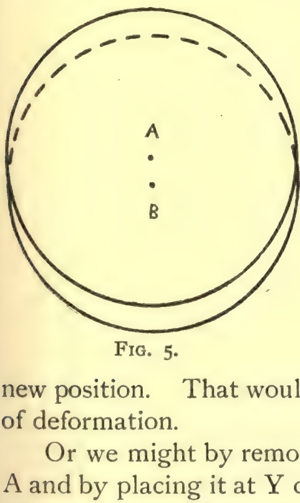


Fig. 5.

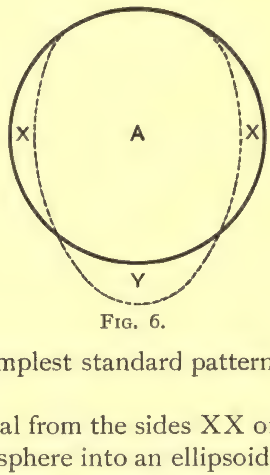


Fig. 6.

new position. That would be the simplest standard pattern of deformation.

Or we might by removing material from the sides XX of A and by placing it at Y convert the sphere into an ellipsoid. That would be the second standard pattern of deformation, the next simplest pattern, and there is a mathematical method of finding how in these cases the regions of elevation and depression will be regularly arranged on the sphere. The method will also tell us how, if one kind of deformation is superposed on another, the regions of elevation and depression will become re-distributed. Finally it will enable

us to analyse any distribution of regions of elevation and depression (such, for example, as obtains on the Earth), and to say by what alterations from the standard patterns, or by what super-impositions of their effects, it can be reached.

Mathematical Distributions of Land and Sea

Returning to the simplest deformation, the spherical harmonic of the first degree, we should find that there would be a division of the surface into two hemispheres; one elevated, one depressed (one all plus units, one all minus units). What the method of analysis will do for us is to give us the line which will separate the two regions of elevation and depression. It will also tell us how high the

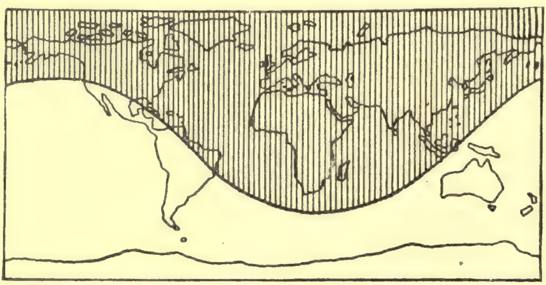


Fig. 7.—Arrangement of land and water on deformed sphere of the first type.

greatest degree of elevation will be. On a map of the world drawn flat the chart of the two regions of elevation and depression will be as in Fig. 7. The central region of greatest elevation will embrace North America, Europe, Asia, Africa and the Arctic in one great continental land area. All south of this becomes a region of depression. This pattern represents the shifting of the surface to the top or bottom side of the sphere.

On an Ellipsoid

Consider now the deformation of the second type, when the spheroid becomes an ellipsoid. The distribution of

areas of elevation and depression becomes now of a different order. Mathematically the result would be an equatorial region of depression which would spread north and south unequally in different parts and form a sort of immense Mediterranean, containing two great basins. This area of depression would lie between and separate a northern region of elevation and a southern region of elevation. The northern region of elevation occupies the northern part of the Atlantic Ocean and runs down to the Equator near Borneo. The southern region of elevation occupies the southern part of the Pacific, and runs up to or beyond the

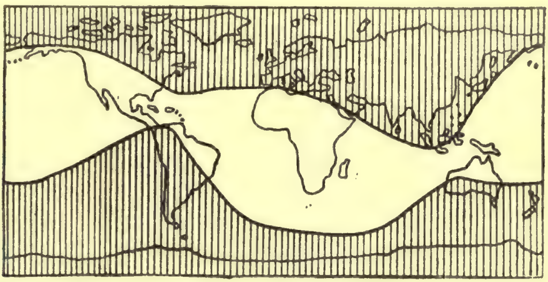


FIG. 8.—Land and water on deformed sphere of second type.

Equator near Peru. The chart of their distribution is shown in Fig. 8.

DISTRIBUTION BY ROTATION

So far we have been considering the two simple types of regular distribution of material which would take place (1) if the bulk were shifted from one hemisphere to another, (2) if the shape were altered from a ball to an egg. Now we come to more complicated considerations. We have, for example, to consider the effect of rotation when it is joined to the fact that the sphere is one-sided or top heavy. One effect of rotation, as we have seen, will be that the parts of greater density of the sphere will tend to fly farther away from the spinning axis than the parts of smaller

density. If the density is greater in one half of the sphere than in the other, the effect will be a sort of furrowed surface. One cause will be super-posed on another and we must now consider a regular "harmonic" distribution of the third degree. How can the surface of the sphere be thus symmetrically divided according to law? Taking our oblong diagram of the planet, we see that the first type of furrowed distribution would be one splitting the surface into zones, depressed and elevated.

If the dark spaces be taken to represent land then we may surmise that under this distribution there would be more land in the northern hemisphere than in the southern; but there would be an Antarctic continent; and that water

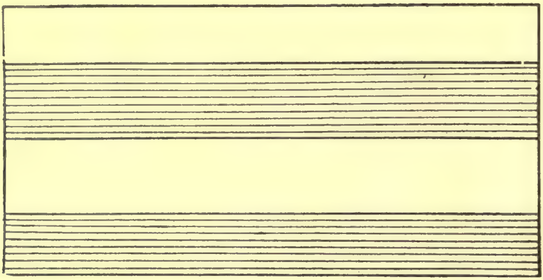


FIG. 9.—Harmonic distribution of land and water on a rotating spheroid.

covered the North Pole. Such would be the simplest consequence of the distribution effected by rotation.

But we have to consider at the same time a harmonic distribution such as might take place when the rotating sphere was lop-sided in weight; or in other words when its centre of gravity was not at its geometrical centre. The second type of distribution which would take this into account would split the oblong diagram up into a different kind of pattern. The pattern looks like a regular arrangement on a tiled floor (Fig. 10); and it is called a *tesseral* arrangement to distinguish it from the *zonal* or belted

arrangement. If we combine these two so as to get a kind of composite photograph which will represent the combined effects of the rotation and of the eccentric position of the centre of gravity we obtain a furrowed surface like that in Fig 11.

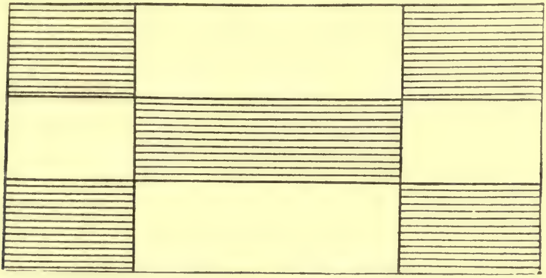


FIG. 10.—Harmonic distribution of land and water on rotating spheroid of unequal density.

But even now we are not at an end of our conditions. Not only is our planet rotating; not only is its distribution of weight lop-sided; but it is not a sphere. It is egg-shaped. What sort of pattern will the elevations and depressions

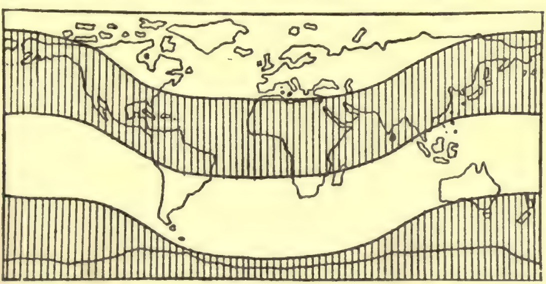


FIG. 11.—Actual distribution of land and water on lop-sided rotating spheroid.

arrange themselves in now? We arrive at a more complicated type of distributions. We have to take into account as heretofore that the egg is spinning and that therefore the denser parts will fly further from the axis than the lighter parts; and as heretofore we must consider that the geometri-

cal centre of the egg is not at its centre of weight. The patterns become therefore still further modified. The tesseral or tile-like pattern splits up not into six but into eight

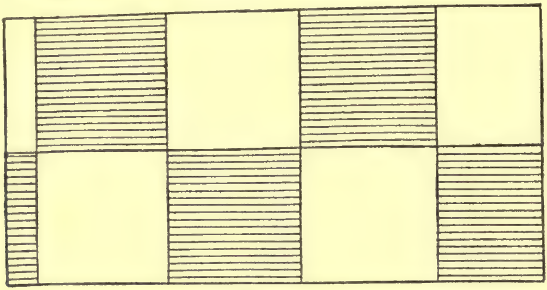


FIG. 12.

tiles. The belted pattern splits into upright sectors, six in number instead of four

COMBINED EFFECTS OF ROTATION, LOP-SIDEDNESS, AND DEFORMATION

The harmonic arrangement of regions of elevation and depression in tiles of the spinning egg may be represented as in Fig. 12.

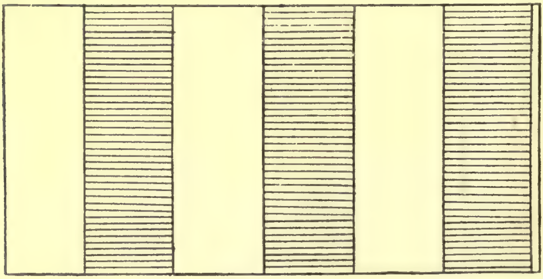


FIG. 13.

The sectional arrangement might be represented by the six sectors of Fig. 13.

(Apparently there are in these two figures more than the

specified number of tiles (ten instead of eight) or of sectors (seven instead of six), but as in a map of the world on Mercator's projection the flat surface is a convention to express a curved one; and the tiles or sectors at the extreme left or right will touch one another when the map is curved to form a cylinder.)

As we combined the two types of distribution arising from the deformation of the sphere, so let us now combine the four types of distribution which arise from the rotation and the eccentricity of the egg. The combined effect of all the harmonic distributions of this third degree is shown in

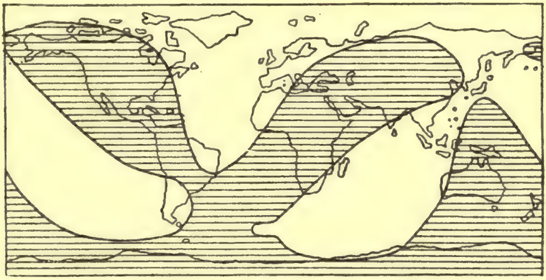


FIG. 14.—Distribution of land and water on rotating deformed egg-shaped planet.

Fig. 14. This represents the distribution of regions of elevation and depression when the sphere is deformed into a shape which is even less regular than an egg and which resembles a fat pear.

We must now ask the reader to shut his eyes for a moment to our rectangular maps and try to see the planet in its natural form as it revolves in space. He must then imagine the stalk of the pear to be in the southern part of Australia and to embrace in a region of elevation Australasia and the Antarctic continent. This elevation will be surrounded on all sides but one (towards South America) by a zone of depression, the waist of the pear. This again will be surrounded on all sides but one (towards Japan) by a

zone of elevation, the protuberant part of the pear; and finally we find the nose of the pear at some point in Africa, the continent of highest mean height above the sea-level.[1]

Another way of regarding it would be as a surface of ridges and furrows. From the South Atlantic run three ridges—one up across the Americas; one up across Africa and Asia; one downwards across Antarctica. From the Sea of Japan run three furrows, one downwards across the Indian Ocean; one downwards across the Pacific; one upwards across the pole.

Finally, however, before we can arrive at the distribution of elevation and depression as it really exists, we must add all our conditions together. We must not pause at the simplest form of distribution which takes into account the dislocation of the sphere's centre of weight; and we cannot regard the furrowing and ridging brought about by rotation as phenomena which stand alone. We must superpose the effects represented by *all* the various harmonic distributions of the first, second, and third degrees. When a composite picture has thus been made of all the elevations and depressions a theoretical figure will be arrived at which will show how and where the approximately equal regions of elevation and depression are situated. Prof. Love has drawn this figure (Fig. 15).

Compare it now with Fig. 4, which represents the *actual* figure of the Earth at 1400 fathoms depth. The resemblance between the actual figure and that which it ought to assume theoretically is certainly very striking. As regards

[1] Prof. Jeans ("The Vibrations and Stability of a Gravitating Planet," "Philosophical Transactions," Vol. CCI, A. 1903) in his first paper on a pear-shaped Earth placed Greenwich as the pole or nose of the broad shaped end of the pear. He afterwards gave this up in favour of the view of Prof. W. J. Sollas who suggested a point in Africa as the alternative. The axis of symmetry of the pear-shaped figure passes through a point where latitude and longtitude are respectively 6° N. and 30° E. and corresponds with the greatest diameter of the Earth.

the contour of the great ocean basins, the theory is confirmed by the facts. Prof. Love prefers not to call the Earth pear shaped, but in accordance with the theory we have endeavoured to elucidate, to describe the Earth as "approximately an ellipsoid with three unequal axes, having its surface

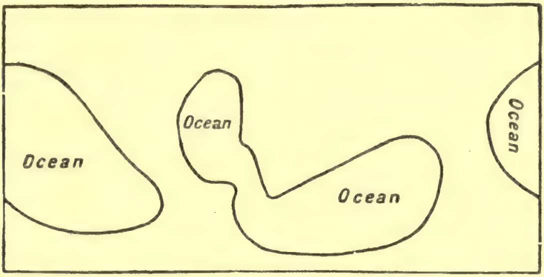


FIG. 15.

furrowed according to the formula for a certain spherical harmonic of the third degree".

The aspect of the theory which it is most necessary to keep in mind is that it shows how the parts of a planetary ball, which is not regular in shape and the weight of which

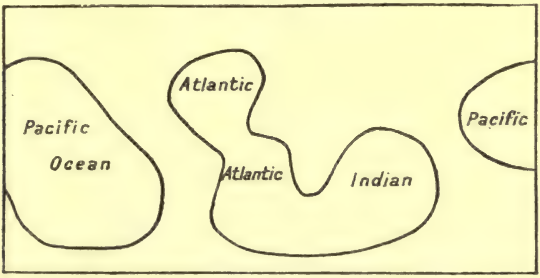


FIG. 16.

is irregularly distributed, can be harmonically arranged. It gives, therefore, in so far as it agrees with the facts, a simple explanation on dynamic grounds of the general distribution of land and sea. It is not exact. For example, it ought mathematically to furnish us with an idea of the *amount* of

depression and elevation in various parts. Here the agreement of the theory with the facts is not so good. The computed elevation is too small in South Africa and in the lower half of South America. It is too great in the Arctic Ocean and in the Mediterranean, which are both deeper than they ought to be. There are other instances where the agreement is not very good. But apart from the fact that the method of computation and the data of elevation and depression are rather rough, it must be remembered that there are causes other than the primary ones which have shaped continents and oceans.

The Periods of Alteration of Shape

The causes themselves have changed in the amount of influence they have brought to bear. The first cause, it will be remembered, was the instability of the Earth due to the fact that it offered an inadequate resistance to compression. But the Earth is harder now. It has been said by Newcomb to be as rigid as hardened steel; and its resistance now is sufficient to keep in check any tendency to gravitational instability. Thus the distance of its centre of gravity from its centre of figure, which was caused by this instability, must be regarded as a survival from a past state in which the resistance to compression was less than it is now.

In the second place, it must be remembered that when we came to consider the more complex distributions of land and sea we were dealing with secondary causes which sprang from the interactions of the simpler primary ones. We should, therefore, expect that the inequalities of the last kind would be smaller than those caused by the great primary inequalities of the sphere. When they are examined and analysed, however, there is not much difference between them. We are, therefore, driven to the conclusion that the distributions of land and sea which we attribute

to the first causes were effected at a time when those causes produced greater effects than they do now. Or in other words, the causes themselves are less potent than they used to be. If they are less potent now it can only be because the sphere itself is still changing, and has always been changing. That is what the mathematicians would lead us to expect.

Sir George Darwin has shown that the egg-shaped irregularity of the figure of a sphere must gradually disappear, destroyed by a species of internal friction. The same thing may be said of a sphere where the centre of gravity is displaced if the sphere eventually becomes rigid enough. Gradually the centre of gravity draws nearer to the centre of figure again.

Symptons of such changes can be made out in the shape of the Earth. For example, in the first harmonic distribution (which we imagined to be due to the simple primary cause that there was more weight in one hemisphere than another) we found that there should have been a great upheaping of land in the neighbourhood of the Crimea. But in the Crimea there are evidences that great subsidences have taken place; and they have occurred in recent geologic ages. We might infer, therefore, that the cause which produced them has been withdrawn or lessened in potency.

The inequalities of the second degree were theoretically caused by the alteration of the sphere into an egg-shaped body: and as a consequence of that cause there ought to have been (see Fig. 8) a great central ocean, a sort of immense Mediterranean which covered Central Africa; and there ought also to have been a North Atlantic continent. It is extremely likely that both these conditions existed. Their disappearance can be explained on the supposition that the causes which produced them have diminished in intensity. Similarly, in parts of the Southern Pacific, the distributions brought about by the egg shape ought to have

produced an elevation: but the distribution brought about by rotation produced depression. In other words, a depression is superposed on an elevation. If the first causes are diminishing then we should expect to find the depression effect dominating the situation; and that is what we do find.

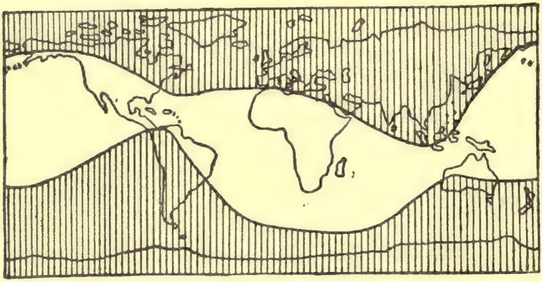


FIG. 17.

The depth of the ocean is gradually increasing in that region as the coral reefs testify.

Prof. Love infers that the inequalities of the first and and second degrees (due to shape and position of centre)

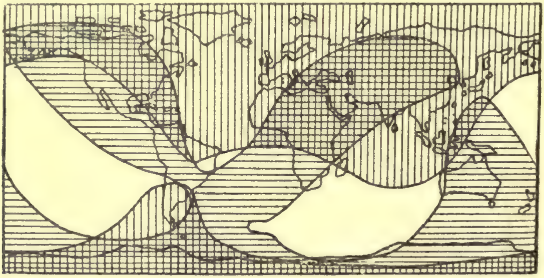


FIG. 18.—In Fig. 18 the elevations brought about by the first and second kinds of causes are shaded vertically: the elevations brought about by the third kind of causes are shaded horizontally.

have progressively diminished compared with the inequalities of the third degree (due to rotation). The general result of such changes would be a gradual diminution of depth and extent of the first oceans; and a compensating

increase in the depth and extent of the later formed oceans. Some idea of the changes thus brought about may be gained by examining a diagram which shows the composite elevations and depressions caused by the first and second set of causes; and separately the elevations and depressions brought about by the third set of causes.

Thus it will be seen that the deep parts of the Atlantic Ocean which border the coasts everywhere from Brazil to Ashanti, and the deep parts of the Indian Ocean, are in a depression which was formed by the third set of causes superposed on the elevation due to the earlier sets of causes.

The deep parts of the Pacific on the western side of America are regions in which an elevation due to the third set of causes is superposed on a depression due to the earlier sets of causes.

Therefore we may perhaps suppose that in the Atlantic and Indian Oceans the direction of world-change may have been such that the ocean has tended to encroach on the land; while in the American Pacific the ocean has retreated and the land has extended. We should in consequence expect different types of coast in the two regions; and we find them.

There are several other pieces of evidence which seem to support the view that the directions of world change have been that of diminishing the prominence of the primary inequalities in comparison with that of a secondary kind.

These changes might manifest themselves on the surface of the Earth spasmodically, when the accumulation of the interior strains reached a point where readjustment became necessary to afford relief.

One other cause is at work: the falling speed of the Earth's rotation. This on the one hand would tend to lessen the heaping up of the waters towards the Equator, while on the other hand it must tend to smooth down the Earth's own protuberance at the Equator. The reduction

of the Earth's figure in this manner would express itself by subsidences and consequent earthquakes in equatorial regions. But the general effect of the two things acting together on the distribution of continent and ocean would be that there would be long periods when the ocean would advance towards the poles and short periods when it would retreat from them.

Prof. Jeans (see previous reference) remarks that the fact that Africa is surrounded by a belt of seas, and this again by a belt of land before the Pacific is reached, points perhaps to a bodily subsidence of the blunt end of the pear, thus displacing the centre of gravity and causing the submergence of the stalk protuberance. This subsidence would tend to produce a line of fracture, which may possibly be repeated by the mountain chains and islands bordering the Pacific and along this great fold of the Earth's surface active movements, often taking the form of violent earthquakes and volcanic eruptions, are still in progress.

CHAPTER VII

VOLCANIC ACTION

Water as a moulding influence—The most ancient rocks—Earth stresses—Volcanic outward movements—The explosive theory of earthquakes—Lines of weakness in the crust of the Earth—Volcanoes and crustal movements—Classification of lavas.

HITHERTO the body of the planet, its core and its inner constitution, have been under consideration. It is now necessary to inquire what changes were produced at its surface and in its outer crust by the agencies which were at work when its general shape and mass were roughly stereotyped. Such agencies, some as great, some greater, some less, are still at work. There is the alteration produced by water; and the alteration produced by that alliance of gas and of heat which results in volcanic action. There are changes produced by air; by heat and cold; and by the presence of vegetation and of organic life in general.

Water as a Moulding Influence

We may suppose that water existed on the Earth before the Earth had grown to its full stature, or had ceased to sweep up planetismal fragments on its way. This water existed perhaps first of all in innumerable lakelets; and water and air therefore moulded the Earth's face as they do to-day, even before it had ceased to grow. The water which washed the Earth's face carried away portions of its skin into the lake pits and coming ocean basins. But water, being charged with carbonic acid (for example) attacks the

alkalis and alkaline earths chiefly; and so carries away some portions of the rock surface more readily than others. The Earth washed by rain, therefore, loses specific gravity while it gains in acidity. This selective action began early in the Earth's history; and even while the planet was growing some portions of its crust were becoming heavier, others growing lighter.

The specific gravity of the land areas came to be smaller than that of those areas submerged by water.

That was an influence which was moulding the Earth's surface, and clearly its effect was cumulative, so that gradually the water areas grew larger and deeper and the land areas narrower and higher. It was comparatively late in the world's history when the balance between them was struck. We must leave for the present the consideration of the era in which life first appeared on the planet; but when it became established the growth of vegetation must have greatly modified the character of the atmosphere and thus a new modifying influence came into play. But though with the arrival of plants and animals the change-producing factors were all present, the parts they played were not necessarily the same as those they play to-day. The early stages of the planet's growth were marked first by the predominance of one, then by the predominance of another agent. The first agent to assert itself most strongly was volcanic action.

First Volcanic Era

It is not proved that we can regard the first period as the greatest period of volcanic activity in the history of the planet; though the suggestion is plausible. It is a suggestion which deals with a state of things in the Earth which cannot be examined. There are reasons for supposing that periods of world-wide volcanic activity, in which igneous or fire-born rocks are vomited, have occurred not once but several times in the planet's history. For example, an examination of the

ancient rocks of Great Britain disclose no fewer than six periods of igneous activity; and there is nothing in the appearance of these successive outbreaks to bear out the idea that there has been any decline of volcanic energy [1] on the Earth. There are even some grounds for believing that the present era is one in which volcanic activity and the outflow of igneous rock matter is a conspicuous feature. So far from the planet being in a state of increasing quiescence, it may be approaching a period of greater activity.

For the purpose of illustration, however, we may presume that the first great volcanic era took place while the Earth was still swelling by addition from outside. The planet by the increasing compression of its parts was accumulating heat at its centre and about its central regions. This heat was moving out to zones where the pressure was less, and was liquefying those rocks which could be liquefied. This action reached a climax, and the igneous rocks poured out on the surface of the Earth, overwhelming the masses which still fell on to the Earth from without and obliterating their effects. Water was present on the Earth and the volcanic explosions due to the action of steam were presumably very great in extent and effect and very frequent; and these effects were vastly greater than those wrought by air or by water unallied with heat. In short, it has been supposed that this period of volcanic energy, or of igneous activity, was not unlike the lunar outbreaks of which the Moon's surface still bears witness. The outbreaks were different in extent and in violence; but they were, as on the Moon, the predominating influence in moulding the Earth's face. It is further suggested that while these great igneous eruptions, and the craters and the cracks from which they proceeded, have been masked by the subsequent growth of the Earth, and by the action of air, water, and vegetation, yet that in

[1] "The Natural History of Igneous Rocks," by Alfred Harker (Methuen), 1908.

the lines of apparent weakness which exist still on the Earth's crust, we may espy some relics of them. There is, for example, one great crack which comes to the surface in various places in Eastern Asia and Western Africa, and stretching from the Dead Sea to Lake Nyassa, reaches the length of 3500 miles.[1]

THE MOST ANCIENT ROCKS

According to the view which we have here set out the lava formation of this period of early volcanic dominances are regarded as forming the underlying rock basis on which all subsequent stratified rocks were laid. This primitive mass of rock has been called the "Archean complex," though it is stipulated that those rock foundations which are exposed to view and which are regarded as the most primitive rocks, are yet the offspring of the later period of this primeval volcanic action. Both in the Old world and the New the lowest accessible rock formations which can be placed in any order of geological chronology were originally surface lava flows. These formations are pierced by enormous insertions or intrusions of granite and other rocks. It is this mass of lava flows, intrusive rocks, all distorted, crumpled, strained and altered by heat which makes up the vast Archean complex. The original surface of the globe when volcanic action and outbursts set in, was far beneath

[1] W. H. Pickering, "Lunar and Hawaiian Physical Features Compound" ("Memoirs of American Academy," Vol. XII, Pt. IV, pp. 177-8): "It is generally thought that terrestrial volcanoes lie along subterranean cracks that do not reach the surface. The volcanoes of the great chain of the Andes lie along a straight crack from Southern Peru to Terra del Fuego, 2500 miles long. The volcanoes of the Aleutian Islands lie along a curved track equally long. . . . There is a crack which come to the surface in various places in Eastern Asia or Western Africa, and stretching from the Dead Sea to Lake Nyassa reaches the enormous length of 3500 miles."

Tschermak has said that the conditions for outbursts of igneous rocks are realized only during a certain stage in the history of a planet—a stage through which the Earth is now passing while the Moon has outlived it.

the present surface, for the Earth's growth was far from complete. Chamberlin and Salisbury believe that the first volcanic surface may have lain as much as 1200 to 1500 miles below the present surface.

Earth Stresses

The crumpled and contorted appearance of these Archean rocks cannot be assigned merely to the fact that they are igneous in origin, and that consequently they boiled up in such a way as to assume these characteristic forms. Some of the Archean rocks, as can be seen in the folds of mountains, show signs of having been compressed on either side; others seem to have been stretched and torn asunder as if by tension of the Earth's crust. Whence arose, in the first instance, the forces which produced these appearances? An ingenious way of accounting for them is to picture the Earth composed of great sectors like the divisions of an orange. On the top of one of these divisions stands a continent. On the one next to it rests ocean. Now if the continental sectors and the oceanic sectors all shrank equally in all their parts, then each sector would sink into its own space and there would be no unequal crowding. But if they sank unequally—if for example the oceanic sectors owing to their greater weight sank first—then we can see that the oceanic wedges would press against the continental wedges. If, again, the wedges themselves shrank unequally, the outer parts of the oceanic sectors might be imagined as thrusting against the outer parts of the continental sectors still more strongly. The foregoing explanation is evidently incomplete, but it affords a glimpse of the possible mechanism by which thrusts and pulls were set into operation, by the effects of changing pressures, and the transference of heat from the Earth's interior outwards.

A further illustration of possible causes of crumpling

and deformation of the rocks is afforded by picturing the outer crust of the Earth as a dome. A dome of rock corresponding to the shape of the Earth, and formed of hard granite rock weighing 180 lb. to the foot and having a crushing strength equal to 25,000 lb. to the square inch, would if unsupported below, be totally incapable of supporting its own weight. It could not sustain one five-hundredth part of it, and would at once fall in. The principle of the dome is brought into play whenever an interior shell is tending to shrink away from an outer one which does not shrink. In this case there is a free outer surface, and a more or less unsupported under surface towards which motion is possible. The dome may, therefore, yield by crushing or bending. But where the thickness of a dome is great, and when for example we have to consider a dome which is as large as a continent or the bed of an ocean, then it cannot move very freely on its underneath side. Therefore, when the dome has to adjust itself to a new form—when it has to settle itself on a new foundation—there will be great strains set up all through it: and there will be some regions where the pressure is extremely great on all sides. The interior part of the planet can only shrink slowly, and it probably shrinks at much the same rate and in much the same way everywhere. Therefore the pressures and strains which its shrinkage causes in the dome are probably simultaneous, and are felt over large areas. Thus there will be a common movement of the dome crust towards the places where there is least resistance. These places will be found at or near the borders of the continents because there the surface is already bent and weakened by the change from land to sea, and by the descent from the land surface to the ocean bottom. Other weak places will be where there have been deep deposits of sediment, such as might accumulate at the mouths of great rivers, or on steep submarine slopes,

It must be remembered that the existence of any land at all depends on the inequalities of the planet's surface. If the Earth were a perfectly smooth ball it would be covered everywhere by its oceans to a depth of about two miles. Not only are the inequalities necessary to the existence of the land: but these inequalities must be renewed from time to time. While no such renewal takes place, the sea creeps over the lower parts of the continents, moving slowly and steadily onwards with a prospect of submerging them. Then comes the check, the reversal, and the oceans withdraw more completely within their basins, while the continents rise and stand out more boldly. To these great periodic movements, or oscillations of the world's surface we have referred before. They leave their impress in the crushing and folding of the rocks; and these folding movements seem to have had extraordinary prevalence in the earliest geologic annals which we can read, for the Archean rocks are almost universally crumpled, and often in all sorts of ways. There is no sign that the folding was then confined to the borders of continents; it seems, on the contrary, to have affected the whole land surface. We may hazard the speculation that in Archean times the crumpling took place much more frequently. In the later history of the planet, when the great sedimentary rocks, the shales, the limestones, the gravels, the sands were laid down, the crumpling seems rather to have taken place at long intervals, thus marking off great time-divisions. These later crumplings are, as we should have expected from the suggestions already made, chiefly confined to what were places of weakness on the Earth's crust.

Volcanic Movements Outward

To the consideration of these processes as agents in mountain building, we shall have to return. For the present, however, we may pursue our examination of volcanic action in contributing to the structure and character of the

planetary crust. The great movements which produce crumpling have by hypothesis resulted from the falling inwards of the crust. Volcanic movements are regarded, on the contrary, as outward movements—though it is quite evident that for every pound of matter moved outwards a pound must move inwards. Keeping that in mind we may divide volcanic action into two kinds, the volcanic action which can be seen at the Earth's surface, and that which though not to be seen is going on below. The planet in its effort to concentrate itself towards its centre, urges its heavier material towards the centre more forcibly than the lighter material. Whether the matter be fluid or solid this must always take place, the heavier constituents pushing down, the lighter being differentially thrust up. In the same way where there are differences of pressure or stress in the rocks the lighter or more movable matter will try to flow from the region of greater stress to that where it is less. The more mobile material takes the path of least resistance. Therefore the portion of the Earth's interior which becomes fluid is always moving outward. Some of these portions, as we have seen, never reach the surface but push themselves into the rocks of the crust and congeal. They are called *intrusive* rocks. Other portions reach the surface and burst out or flow out, and become *extrusive* rocks. The intrusive rocks find their way into fissures and become *dikes;* into chimney-like passages where they form *pipes* or *plugs*, like the famous spine or needle which was forced like a piston rod up Mt. Pelé. If the lava solidifies between other beds of rock it forms into *sills;* and it has other forms known as *laccoliths* and *batholiths*—when it is massed in great quantities underground.

When the molten rock reaches the surface it bursts out or flows out. It is more likely to flow out when it has a great fissure through which it can find an unrestricted passage. The stupendous outflows with which geologists

are familiar appear to have made their appearance most often in this way. The chief fissure eruptions of recent geologic eras are the vast basaltic floods of Iceland. Further back in Tertiary times, there was an outflow in Idaho, Oregon, and Washington in which some 200,000 square miles were covered with successive sheets of lava to a depth in places of 2000 feet. Earlier in the Cretaceous period there were flows which covered the region known as the Deccan in India to a depth of between 4000 and 6000 feet. Still earlier, in the period before the Cambrian, an even more prolonged succession of lava flows covered nearly all the area of the Lake Superior basin, and extended beyond it, building up a series of volcanic rocks 20,000 feet in thickness. In all these cases there is little evidence of explosive or other violent action—few beds of ashes, or cinders. We may suppose then that the lava welled out and spread itself fluently over the surrounding surface. Massive outflows of this kind, though they have always left more conspicuous traces than any other form of volcanic action, are no longer the dominant type. The local volcano in which the lava is forced out through short ducts, or perhaps short fissures, is now the most frequent example of *extrusive* action. Midway between these two types of volcanic action, and that other type in which the lava merely intrudes into other rocks, is a type where the lava seems to come so near the surface without coming forth from it, that it develops explosive forces though no lava comes to light.

At the present time the number of more or less active volcanoes on the Earth's surface is perhaps 350. In the period to which we assign the Archean rocks, it is possible that the Earth was as thickly pitted with vents as the Moon now appears to be; but in the ages between then and now the distribution of volcanic action over the surface seems to have been in a general way very much the same at

the present time. There is nothing to show that there has been a steady decline in volcanic action: though there are signs that it has risen and fallen, risen and fallen again.

The Explosive Theory of Earthquakes

A very ingenious attempt has been made by a mathematician, Dr. T. J. See,[1] of the U. S. Naval Observatory, California, to show that the same causes which produce volcanic eruptions are concerned also in the formation of mountains, and that both arise from the leakage of the waters of the oceans, seas, and lakes into the hot strata beneath the Earth's skin. Then the contact of water and heat gives rise to steam, and thus sets in motion forces which may at once produce volcanic eruptions, or which after remaining latent for long periods may give rise to earthquakes or more deliberate Earth-movements. This is perhaps the oldest of all reasoned beliefs as to the causes of volcanoes, or of earthquakes; and has been called the explosive theory of Earth movements. Dr. See marshals many facts to support his resuscitation of this theory. Volcanoes are most often found along coast lines where a mountainous country slopes swiftly to great ocean depths—witness the Andes; or the highlands of Japan in proximity to the depths of the Pacific; or Vesuvius and Etna on the borders of the Mediterranean. These are districts also where earthquake tremors most frequently make themselves felt. We shall have again to refer to this theory in speaking of the causes of earthquakes; but its specific relevancy at this point is that Dr. See endeavours to explain by it the building of mountain ranges.

[1] "The Cause of Earthquakes, Mountain Formations, and Kindred Phenomena connected with the Physics of the Earth," by T. J. J. See ("Proc. of American Philosophical Society," Vol. XLV (1907), pp. 274 *et seq.*). Further papers on the same subject: Vol. XLVI (1907), pp. 369 *et seq.*; pp. 190 *et seq.*; Vol. XLVIII (1908), pp. 157 *et seq.*

Under the action of the great pressures at the bottom of the deep sea, he supposes that the water penetrates the rocks and reaches considerable depths in the Earth's surface. Here it is held and absorbed by the material under very great pressures and at high temperatures. Under favourable conditions this highly heated water becomes explosive steam and produces an earthquake. More than that, it blows out a portion of the ocean bed. Material is displaced; water flows into the cavity produced; and more lava is injected under the surface of the bed on either side of the cavity. In effect, though not in method, these continuous steam explosions produce a trench with the excavated material rising on either side of it. If the lava which is forced underneath the bed in which the trench or cavity is dug, moves seaward a new ridge of submarine mountains may be gradually built up there. Dr. See regards the ridge of the Aleutian Isles, between North America and Asia, as an example of this kind. If the lava is forced towards the land the coast is raised, or the mountains are still further lifted up. If the lava is injected both ways parallel mountain chains would be produced, and the sea would ultimately drain out of the trench between them. The objections to Dr. See's hypothesis are that we have no warrant for assuming continuous leakage down to the great depths at which it is believed the larger number of great earthquakes originate; and we do not know that water absorbed and diffused in the rocks at great depths would have explosive properties.

It is necessary, in order to account for the explosions, to imagine some other cause which changes the pressure in the rocks where this water is held in absorption. In short, to quote Dr. C. G. Knott,[1] the explosion of the steam is an effect of deeper-seated causes which relieve the pressure in weak

[1] "The Physics of Earthquake Phenomena," by C. G. Knott (Clarendon Press), p. 271.

places. This pulls the trigger, and the explosive force which has been latent is let loose.

Other more general objections to the idea that volcanoes are essentially connected with steam explosions are that volcanoes are not distributed equally or proportionally about the oceans as if they were dependent on them. The Pacific is the most favourable instance: but there are many volcanoes about the Mediterranean, which is not a great body of water, and which supports, as we might say, a good many more volcanoes relatively than the Atlantic. There are, it is true, no volcanoes in the interior of Asia and Africa, but there were once.

Lines of Weakness in the Earth's Crust

It has been more plausibly urged that both old and recent volcanoes are distributed along ancient lines of weakness in the planet's crust; or along those portions of the crust which have undergone notable changes in position. A great world ridge stretches from Cape Horn, the southernmost part of South America, to Alaska in North America; and it is then continued along the East coast of Asia. This ridge is dotted throughout with active volcanoes or with those that are recently extinct. Then there is the wavy line of mountainous wrinkles which borders the Mediterranean and stretches eastwards to the islands of Polynesia. That also embraces notable volcanic tracts. The volcanic region in the neighbourhood of Jamaica (the Antillean region) lies where the southern angle of the North American continental block forms the northern angle of the South American continental block; and where also the depths of the North Atlantic approach the abysses of the Pacific—separated only by the Isthmus of Panama. Again the volcanoes of the Java-Philippine region lie where Asia projects a tongue towards Australia, and the region just separates the Pacific depths from those of the Indian Ocean. The Icelandic

region is a point between the North American and European continental segments on the one hand, and the Atlantic and Arctic oceanic depths on the other. The New Zealand volcanic region is at a similar "four cross-roads" point with regard to the Australian and Antarctic continents and the Pacific and Southern Ocean segments. Nearly all these volcanic areas have therefore two land segments on one side of them and two ocean segments on the other. The "lines of weakness" theory thus satisfies the grouping of a good many volcanoes. But there are many others left outside this arrangement, and enough of them to suggest that their activity is not wholly dependent on any causes which we may espy on the surface. These surface conditions may indeed modify the action and distribution of volcanoes; but the actual cause of them lies below the crust and beyond the influence even of the movements of what Prof. Chamberlin has called the master segments of the Earth's crust.

Volcanoes and Crustal Movements

It is difficult indeed to find any cause apparent to us in the nature or movements of the Earth's surface which will satisfactorily account for the distribution of volcanoes. It has been suggested that the Earth is growing less flattened at the Poles as its speed of rotation decreases; and that this might cause strains on the crust at the Equator and the Poles of the planet which would cause volcanic action. But there is no evidence to support the view; and the fact that some volcanoes lie in curved lines and some in straight lines, and others in irregular groups, is another reason for refusing to refer the primary cause of them to movements of the crust.

Some observations have lent force to the supposition that where volcanoes are active the region about them is rising. Dr. See has used the evident rising of the area

of the west coast of South America to strengthen his theory that lava is being injected under this mountainous region. Charles Darwin called attention to the raised beaches at many points along this coast; and these show either that the land is rising, or else that some ocean basin in their neighbourhood is sinking. Sir Thomas Holditch, whose journeys in southern South America are recent, has observed that whereas there are raised beaches to support the idea of rising land, yet at many points the remains of forests are sunk beneath the sea thus indicating land depression; and his observations have been confirmed by other investigators. It seems most likely that both in old volcanic regions and in active ones the areas can be partly sinking and partly rising, and that movement of either kind will be connected with the expulsion of lava.[1]

Classification of Lavas

Other questions are suggested by an examination of the expelled lavas. Would it not be possible by classifying the kinds of lava to arrive at some conclusions respecting their origin and age? Thus, throughout the coast belt of the Andes all the volcanic rocks are very much alike; whereas in the small Mediterranean group of volcanic islands there are varieties of lava which are widely different and which belong to specialised types. Lavas are not simply melted rock. They are rather minerals dissolved in other minerals; and in this mutual solution gases enter. When we are dealing with metals like iron

[1] Captain H. G. Lyons has shown that there is a frequent and differential movement of great blocks of country, throughout the region immediately surrounding Lake Victoria, lasting over several years, and perceptible chiefly north-east and north-west of the lake ("The Physiography of the Nile River and its Basins," Cairo National Printing Dept., 1906, "The Rains of the Nile Basin and the Nile Flood of 1908, by Captain H. G. Lyons, F.R.S., Survey Dep. Papers, No 14, Cairo, 1909).

STROMBOLI ON 20 APRIL, 1904: SHOWING AN EXPLOSION OF THE 'VULCANIAN' TYPE

From a photograph by Dr. Tempest Anderson

and copper we know that they will solidify on cooling at definite temperatures, because they melt at definite temperatures. But such laws cannot be applied systematically to lavas. Very often they cool like liquid matter which freezes—especially if they are cooled suddenly—but more often the mixed solutions which constitute them crystallize into solidity according to the laws of solution, which are not the same as those connecting melting and temperature.

The temperature of lavas is still a matter of conjecture. It is known from observation to be higher than that of melting silver or copper; and it is probably safe to assume that it may be in some cases as great as 3000° F. when it reaches the surface. But such a temperature must be below that with which the lava was charged in subterranean depths, because some heat must be lost in rising. Volcanic explosions are very generally accompanied by steam; and if we are to suppose that any large proportion of the gases of lava are derived from waters which joined the lava in its upward course, then the energy consumed in raising the water to the higher temperature of the lava must be subtracted from the original heat.

This is an important point because it has been suggested that lavas may be formed by a kind of hot-water boiling or simmering which might take place at moderate temperatures. But evidently the starting temperatures are high and the maintenance of the lavas for a long time in a boiling condition also implies that they had a temperature higher than the rock boiling-point to begin with. This would be especially true if the lava boiling is caused by percolating surface waters. If, on the other hand, the lava gases come from great depths they may bring heat of their own with them. It is not possible to say at what depth the lava does take its origin. Attempts have been made to determine it by ascertaining the points below the surface

from which the earthquakes which accompany eruptions originate. Such estimates range from seven miles to thirty. Probably something under ten miles is nearest the truth; but in any case this does not tell us where the lava began, but only the point at which it began to split the rock through which it was passing.

It will be necessary to return to a consideration of some of these questions in dealing with the influence of volcanic action in moulding the surface of the Earth in the known geologic eras; but it will be seen that the observations of volcanic action and results do not afford anything more than a speculative basis for a great volcanic era in that stage of the planet's evolution which preceded the laying down of the sedimentary rocks.

CHAPTER VIII

THE ATMOSPHERE

Extent of planetary atmosphere—Planetary history of gases—Nitrogen, oxygen, water vapour, carbon dioxide—Volcanic contributions—Balance of gases.

WHEN we quote from Milton or from Shakespeare the lines which speak of the music of the spheres, the

> . . . harmony
> That sits upon the nine infolded spheres

we hardly recognize in the quotation the relics of an astronomical superstition which was held by the Chaldeans. They pictured the universe as a spherical one; and the planets and stars as set in a series of concentric orbs or spheres, each so perfectly transparent that bodies in the outer ones were visible through all the intervening ones. As Ptolemy drew the spheres the Earth was encircled by air and fire. Beyond these orbs was the encircling sphere of the Moon and beyond that again were the concentric spheres of the Sun and the stars.

Extent of Planetary Atmosphere

Geology has no use for any but the smallest fragment of these beliefs. It is, however, convenient to regard the planet itself as made up of concentric spheres—the lithosphere or globe of rock, the hydrosphere, and the atmosphere; and to suppose that before the planet was encircled by its waters it was surrounded by the atmosphere which

held them in suspension. The Earth's atmosphere which, roughly speaking, we say consists of mixed oxygen and nitrogen, consists more truly of many more gases and emanations. The first class of such gases are all those which at the temperature and pressures existing at the planet's surface are gaseous bodies. Carbonic acid, for example, is a gas on the Earth though on the Moon it would be a solid, and some think that on Mars it constitutes the planet's snowy polar caps.[1] Other gases argon, neon, xenon, krypton, helium have been found in small quantities in the Earth's atmosphere, and some of them seem to be discoverable in greater quantity at great heights. All these we may class, whatever their quantity, as permanent gases of the Earth's atmosphere. The second class of gases are those which are fluctuating in quantity according to the conditions which produce them; and the chief among these is the vapour of water. Theoretically every substance, solid or liquid, discharges into the atmosphere particles which may become transient constituents of it. We have the evidence of our noses that innumerable volatile bodies which give off odours, do so; and radium, it has been shown, gives off a heavy gas which has been called radium emanation. Practically, this and other emanations, exist in such small quantities as to be inappreciable: but it is not impossible that in other conditions they would assume a much greater proportion.

At present the atmosphere, which is estimated at a weight of about $\frac{1}{1,200,000}$ of that of the Earth encloses it in a layer perhaps 100 to 200 miles in thickness. Theoretically its thickness is far greater than that, because it does not entirely cease to exist till the limits of the Earth's gravitative action are passed. In the lower, denser portion of the atmosphere the molecules of its gases are flying hither

[1] "Is Mars Habitable?" by A. Russell Wallace, F.R.S., pp. 96, 97 (Macmillan, 1909).

and thither in every direction equally. But in the thin heights of the atmosphere some of the molecules flying upwards do not come into collision with others, but leap like fountains whose particles are only drawn back by the Earth's attraction; and some may start on their upward path so swiftly that they overleap the 620,000 miles which are the limits of the Earth's influence, and pass away never to return. On the other hand, any wandering molecules of gas which are travelling in the solar system and which come within 620,000 miles of the Earth in their journey, will be captured by the planet.

When the Earth was growing it may have been at one time destitute of atmosphere altogether, for the simple reason that its bulk did not possess sufficient gravitative attraction to hold an atmosphere together. But as it grew larger it became able to fold such a blanket about it; and it was perpetually deriving atmospheric gases from its own interior material, and from the new meteoric substances which were adding to its size and attraction. What the earliest atmosphere was made of, must have depended largely on the gaseous molecules which were rushing into the Earth's sphere of attraction; that again must partly have depended on what gases existed in the great parent nebula from which the Earth was first derived. There is evidently at the present time a great deal of hydrogen in the Sun: but the Earth could never have held it largely in a free state.

Shut up in meteorites and in the crystalline rocks are hydrogen, carbonic acid, carbon monoxide, with marsh gas and nitrogen in small amounts. We may believe, therefore, that these were the gases shut up in the rocks of the early Earth; and that hydrogen combined with some of them. There is experimental ground for believing that it might have been able to join with some of the compounds of oxygen to form water vapour. Therefore for the constituents

of the earliest atmosphere we might have chiefly water vapour, carbonic acid, and nitrogen.

Planetary History of Gases

These gases, splitting up and combining with different compounds, would be present in the atmosphere according to the ability of the Earth to keep them to its side; and the heavier the molecules of the gas the larger the quantity of that gas would the Earth retain. Thus we should suspect that carbonic acid gas was held before oxygen and for a still longer time before nitrogen, and all these a notable time before the vapour of water. The amount of nitrogen shut up in rocks and meteorites is relatively small and there was perhaps not much of it in the early atmosphere. But nitrogen is what is called a chemically inert gas. It does not readily enter into combination. Like Mr. Rudyard Kipling's cat, it "walks by itself". Consequently it may be supposed to have been increasing in volume, seldom parting with any of its accretions to invest them in any neighbouring compound, since the atmosphere began. Nitrogen thus attained its present dominance. Water vapour also increased as soon as the Earth was bulky enough to hold it. There would always be abundant sources of supply for it in the Earth's constituents.

Oxygen has a more uncertain history. It is never free either in crystalline rocks or in meteorites. Volcanoes expel it in their eruptions: but it does not necessarily come from the deep interior of the Earth on that account. It may have been picked up by the mounting lava on the way upwards, from surface rocks or from permeating waters. It exists in the Sun and therefore it probably existed in the parent nebula from which sprang the Sun and all its planets and all its planetary fragments. From the flying fragments of the nebula the Earth may have picked it up slowly, after the acquisition of heavier gases had begun. Or possibly

the planetismals when they impinged on the Earth's growing mass may have set up the collision powerful enough chemical action, and enough heat, to release oxygen from water vapour. When plant life finally began the plants would be sources of oxygen and would add it gradually to the atmosphere.

The problem of the atmosphere was of course considered by the great physicists of the last century, who like Lord Kelvin, strove to fit Laplace's nebular hypothesis with the facts. They regarded the atmosphere as a sort of residuum which remained unused when all the other possible combinations of the elements had taken place. Nitrogen, oxygen, water vapour, carbonic acid were thus like by-products left over when the rocks were made. It is quite easy to believe that the reluctant nitrogen might have remained unwedded: but an element with such an affectionate disposition as oxygen could scarcely have found itself left without an affinity. Nor is it easy to believe that the enormous volumes of water now in the sea, and the enormous amount of carbonic acid gas in the coal and the chalk, were ever loose in the atmosphere before they thus merged their separate identity in the strata or the oceans. Even the carbonates of the Earth's crust if suddenly turned into gas would increase the volume of the atmosphere two hundred fold. Apart from any other consideration the Earth was never big enough or strong enough to wrap such an atmosphere about its bulk and keep it there. The atmosphere, we may then take it, was never larger than it is now: though it may have been differently constituted.

To another physicist of the last century, the Rev. Osmund Fisher, F.R.S., who at the time of writing (1911) has lately entered on his ninety-second year, we are indebted to the first development of the idea that the gas was originally shut up in the molten crust and has escaped from it. In "The Physics of the Earth's Crust"[1] he defended the hypothesis

[1] See previous references, Chapter V.

that beneath the crust was a mass of molten rock holding gas in solution; and he regarded volcanic eruptions as being the symptoms which followed the breaking through of the crust by this gaseo-molten lava. He denied, however, that the gases which volcanoes give off came from the water of the sea: and he claimed that both the oxygen and the saline matters which lavas display were really of deeper origin; and that therefore the Earth's molten interior must have shut up in both the substance of water and the materials of the salts. If he were asked how this water substance came to be there he would reply that at the earliest periods of the solid globe, the waters of the Earth did not all lie over it in clouds of vapour, but such parts of them as the molten rocks could accommodate were united in solution with these rocks. Indeed in the earliest days these rocky bases were themselves possibly in a gaseous state. . . . "If oxygen was then present, it is probable that hydrogen was likewise, and that while as cooling proceeded the Earth's bases took their share of the oxygen, so the hydrogen took its share also. In this manner water substance would have been a constituent of the molten magma just as the other elements and minerals." This conception of the origin of the waters gives a new significance to the phrase "the waters that are under the Earth".

Volcanic Contributions

It seems at any rate legitimate to suppose that the earliest water vapour and the earliest carbonic acid were expelled in the first volcanic era. A volcano in our own day belches forth immense quantities of steam: and we have supposed that in the childhood of the Earth there were many volcanoes and greater ones. If—though we only put this forward as a supposition—there had ever been a period of volcanic activity on the Earth resembling that of which the Moon shows traces, there would have been supply

taps enough to furnish, in vapour, all the waters of all the oceans.

There is even stronger reason for believing that volcanoes supplied the carbonic acid. Boussingault calculated that the volcano of Cotopaxi alone gives off as much carbonic acid as the whole breathing city of Paris—about 750,000 cubic yards—a day: and evidently a number of volcanoes discharging at this rate would soon form a vast atmosphere of the gas. Possibly when organic life began the atmosphere consisted chiefly of carbonic acid, with some nitrogen. Plants can grow in such an atmosphere: and as has already been suggested they would contribute oxygen. If this theory were entirely acceptable the great primeval forests might be regarded as the manufacturers of oxygen for animals; and it would be possible to suppose that the sluggish animal life that first appeared was suited by an atmosphere of little oxygen and that the increase of oxygen helped to evolve, and to preserve the more active animals at the expense of the others.

We may devote a little space to examining this idea. If Boussingault's calculations about the amount of carbonic acid gas exhaled by the life of a large city be followed out we should find that the 1,500 million people of the world pour into the atmosphere about 262,800 million cubic yards a day.[1] Giraudin puts the production of carbonic acid gas of animals at something more than double that of man, let us say 1,095,000 million *kilogrammes a year.* But there remain other sources of the gas. All plants, while they decompose carbonic acid as part of their method of nutrition, breathe in the same manner as animals and exhale carbonic acid as well as oxygen. All the fires of the world; the slow production of the gas by decaying vegetable matter; the mineral springs and the volcanoes—all contribute. It is difficult to form any idea of the total quantity of the gas

[1] Russell, Smithsonian Miscellaneous Collections.

exhaled: but Armand Gautier comes to the conclusion that the amount cannot be very far short of five billion kilogrammes a year. The weight of the whole atmosphere is about a hundred thousand times greater.

Balance of Gases

The relationship between the carbonic acid given off by men and the carbon and oxygen exchange of plants has several aspects. It has been calculated that about 2½ acres of forest produce each year 3000 kilogrammes of carbon in the form of wood and leaves. During half a year of active growth the trees must draw from the air about 5600 cubic yards of carbonic acid and give in exchange about the same amount of oxygen; with a field of oats about the same proportion is true. Thirty-two persons give off as much carbonic acid as is taken in by two and a half acres of oats and forest and they use up about as much oxygen as the surface of field or forest produces. An acre, therefore, compensates for about twelve or thirteen persons.

The late Prof. Mendeléef adopted different methods of calculation in trying to show that the atmosphere of the Earth has changed in the course of the ages. He calculated the weight of the atmosphere as 5,100 billion tons and the weight of the oxygen, therefore, as about 2,000 billion tons or rather less than half of this; and he assumed that the innumerable processes which swallow oxygen are compensated by the plant processes. But he found that the plants on the dry land contributed not more than 100,000 tons of oxygen, which is an insignificant fraction of the entire mass of oxygen of the air. It is not likely that the gaseous balance between the exhalations of the plants and of the animals can be exact: and it is an open question whether more carbonic acid is produced than can be combined or broken up, or whether more is combined and

broken up than is produced. Two authorities, T. Stevenson and Phipson, think that carbonic acid is decreasing.

Dr. Krogh of Copenhagen is of an opposite opinion. He holds that there are some signs of an increase of carbonic acid. One of them is that over the sea the pressure of the gas is lower than over the land. This would appear to mean that the pressure of carbonic acid *in the air* is constantly greater than the pressure of carbonic acid *in the sea*, and that therefore the air must be steadily deriving supplies of the gas from some source by which the difference in pressure is maintained.

An alteration in the quantity of carbonic acid would produce considerable results not only chemically, but in climate, because the gas is a great absorber of heat.

There are, however, compensatory provisions which would make the increase of the gas very slow. If the pressure of it increases plants absorb some of it and give off some oxygen. The waters of the Earth form an even more important regulating apparatus. The chemical combinations into which carbonic acid can enter with the sea are reversible. One of the effects of this is that there is a constant interchange of carbonic acid between the waters and the air above them. If there is greater pressure of carbonic acid in the air the waters absorb more. At present the amount of carbonic acid in the air amounts to about three parts in 10,000. The quantity in the whole of the sea is about twenty-seven times as much as this. In order to increase the carbonic acid in the air to four parts in 10,000 it would be necessary in the first place to add one-third of the amount already present. But that would not be enough, for the sea would continue to absorb it, and according to Dr. Krogh's experiments, if the ocean had to be brought into equilibrium with the altered atmosphere there would have to be *another addition of twice the amount* of the carbonic acid now present in the air. It would mean an

addition to the air, from some land sources, of more than 5½ billions of tons of carbonic acid. A calculation of this kind helps to explain the constancy of the atmosphere and to indicate the magnitude of changes required to produce any variation in it. Moreover, this absorption of gas by the sea is not a slow process. It takes place with remarkable rapidity, and the ocean responds instantly and sensitively. When in the early volcanic era the pressure of carbonic acid gas was much greater, and the water warmer, this provision of interchange must have greatly influenced the formation of the sedimentary strata.

CHAPTER IX

THE ANCIENT SEA

Effect of life on the sea—Quinton's hypothesis of the identity of the body fluid of living animals with the ancient sea—Modifications of the hypothesis—Permanence of fundamental characters—Bodies of water compared with breathing organisms—Internal respiration of a lake.

WHETHER we think of the Earth as a cooling mass of liquid, or as a globe which after it had solidified continued to add to its bulk by contributions drawn from without, we cannot escape the presumption that at some point in its early history it must have been a great deal hotter at the surface than at present. Similarly, whether we consider its atmosphere as a mass of gas which once was greater; or as one which grew by additions both from within and without as the Earth became more capable of holding it, we may reasonably infer that it was once a warmer atmosphere. Its temperature was, however, continually falling. When it fell low enough the water-vapour in it would condense into liquid. The liquid would promptly be evaporated; would be condensed again: evaporated again—and so on in a much more speedy cycle and with more profound chemical and physical disturbances than today. Figuier, a generation ago, pictured the early globe as overwhelmed in floods of continuous rain: its frame shaken by unending earthquakes, its atmosphere trembling with perpetual thunderstorms; and perhaps the picture has warrant in probability.

At last, however, the water settled into hollows. There

would be places on the Earth where the temperature of the crust was lower than elsewhere and here the first seas would be formed.

Prof. A. B. Macallum [1] has suggested that the primitive crust would be thin and yielding, and whenever a considerable quantity of water fell on it would become depressed, and would thus convert itself into the hollows for the first ocean beds. The composition of these first oceans would be very different from that of the modern ones. At first, for a very short time, the water in them would be almost pure: but soon salts would accumulate. They would be derived from the crust of the Earth in which the water lay in hollows; and, also, from the salts present in the rocks of the dry land and brought to the seas by the rivers. In the waters of the first rivers the salts would be present in quantities depending on the amounts of them in the rocks and also on the extent to which they were soluble in water. The composition of the seas would rapidly become the same as that of the rivers. It would probably, therefore, have potassium and sodium in equal amounts; possibly magnesium would be more abundant than sodium; and calcium would be more abundant than either.

Effect of Life in the Sea

Now suppose that life appears in the sea. This would make an alteration in the composition of the oceans, because life like a chemical re-agent would group the salts in new forms and combinations. Calcium would at some date sooner or later be taken out of solution and cast down as a solid, because this element would be appropriated by some of the living organisms to form their living skeletons; and when they died their skeletons would sink to the sea bottom and accumulate.

Some magnesium would also be thrown down in the

[1] "Transactions Canadian Institute," Vol. VII, Part III, 1904.

same way. That is shown by the presence of this element in association with lime in the form of magnesium limestone. Potassium would also be liberated—by a rather complicated chemical process in which the action of life acts as the trigger to set the forces in motion. In this manner and by other means the excess of potassium originally in the waters of the sea would be gradually solidified out. Thus the calcium and potassium gradually diminished. It was otherwise with the sodium. Sodium is not removed from the sea to any great extent. Small seas may dry up and their salt contents pass from liquids to solids, but the process cannot take place on a very large scale; and the work done by evaporation is undone by rainfall. During all the past history of the Earth sodium (and salt) has been dissolved out of the rocks and carried down to the sea by the rivers, and so has gradually been increasing in amount.

Thus because of the chemical actions of the salts among themselves, because of the action of living things, because of the dissolving action of the rivers on the rocks of the land —the composition of the seas has always been changing. Lime and potassium have been decreasing: sodium has been increasing. Magnesium has also been increasing.

Quinton's Hypothesis

But we have another means of arriving at the composition of the early sea; though it is but a theory. The idea was conceived independently by Prof. A. B. Macallum, and by a physiologist, one of the assistants at the Collège de France, R. Quinton.[1] Quinton's hypothesis, as sometimes it is called, suggests that in the blood of living animals we have a clue to the temperature and composition of the early sea. The higher animals are made up of vast colonies of living cells. These cells are bound together in all kinds of complex ways, and are of many different kinds. There are

[1] "L'Eau de Mer Organique," Masson, Paris, 1904.

the red blood corpuscles, and the white blood corpuscles; there is the "dead matter" which the living cells manufacture or secrete, such as bone matter, or muscle fibre; there are also milk and other secretions which the cells produce. Lastly there is the vital fluid in which these cells are all bathed. The blood, for example, if deprived of its red and white corpuscles, is a slightly salt fluid. Chemists would call it a "physiological salt solution". It is the universal circulating fluid which bathes all the cells and which, in various forms, is necessary to their life and existence.

Now Quinton avers that this vital fluid, which is comparable with the waters in which the lower sea animals live represents the same thing in the higher animals. The only distinction is that the higher animals are all closed up, or sealed up, by membranes, and in this way they carry about with them the fluid in which their cells bathe. Quinton, in short, compares man to a marine aquarium, filled, however, not with present day sea water, but with a sea water which resembles that of the early ocean in which his "lower animal" ancestors bathed millions of years ago. Or he compares him to the culture tube of the bacteriologist. His body is the glass tube; the bacterial growth inside it is the living cell matter: the nutrient fluid is the blood serum, the vital medium which makes it possible for the living growth to go on.

It will be seen that Quinton's hypothesis demands that animal life must have begun in the sea. That is not certain; but most geologists accept it as a convenient belief; and we may temporarily take it for granted. That being so, it is reasonable to suppose that there should be some tendency among animals with a closed body cavity to retain the ancestral composition of the vital fluid. Those first organisms which originated in the sea were organisms with a single cell—the simplest living things. From them both

plants and animals subsequently sprang. They lived bathed in water in which were dissolved salts in certain proportions. But these proportions, as we have seen, were continually altering. The incoming rivers altered the proportion. The Sun's evaporation altered the proportion. It is possible that the sea animals remained open to the enveloping sea water while its proportions suited their growth and development, but when it became too strong (shall we say?) for them, they closed themselves by membranes or migrated towards the land.

Quinton suggests that they took the earliest ocean fluid with them in their sealed bodies ; and that their descendants have retained it, or something very like it, ever since. If we accepted this belief unconditionally—then the blood fluid of mammals being a warm, salty liquid, we should suppose that the early ocean, almost identical in composition with this liquid, was a warm ocean with a temperature about 111° F. and about seven to eight parts in a thousand of salty matter, chiefly sodium chloride.

This belief cannot, however, be accepted unconditionally because it seems most likely that the ocean *had altered in composition* before it drove the stronger and more adaptable cells to migrate to the land or to protect themselves with membranes or in other ways.

Criticisms of the Hypothesis

Dr. A. C. Lane,[1] while commending the suggestiveness of Quinton's theory offers some illuminating criticisms on it in minor points. For example, the temperature of 111° F. which Quinton assigns to the early ocean is arrived at by a comparison with the hottest blood temperature of birds. It is certainly a remarkable fact that from the tropics to the poles the temperature of the vertebrate animals hardly

[1] American Association for the Advancement of Science, Presidential Address to Section E (Geology), 1907.

varies more than ten degrees from this figure. But it is possible that the processes of oxidation and combustion have raised this figure to its present height—a height which is best suited to the work which the cells of land animals have to do, but which is possibly much higher than that possessed by the vital fluid when animals first emerged from the sea. However it is not difficult to believe that the early sea, and therefore the early vital fluid, was warmer. Van't Hoff, the chemist, finds evidence of a warmer ocean in the Strassfurt salt deposits; and the wide extent of corals and ferns and carboniferous deposits towards both the North and South Poles, are hints of a warmer climate. If we are to accept the doctrine of a warmer sea, then the early fish may not have been cold-blooded animals at all, but active warm-blooded creatures whose blood temperature was that of the warm ocean around them. Such a warmer ocean would possibly accelerate the activity of life and of evolution.

Again Quinton infers that the early ocean had between seven and eight parts per thousand of salts. This is the same as that of the blood fluid of birds, which seems to have kept the temperature most nearly constant and may be supposed to have kept nearly the same composition of vital fluid also. But there are many difficulties in the way of accepting this theory without reservations; and it seems more likely that the "vital medium," as we know it now, does not represent, exactly, the early ocean in saltness any more than in temperature. It does, however, seem to represent the ocean at the end of the era of Cambrian strata; not long before the time when the first fishes are known to have existed but long after life had begun. The evidence then goes to support Prof. Macallum's belief that the present body fluid represents the ocean water at the time when the body cavity in the process of evolution was becoming closed—rather than Quinton's hypothesis that the body fluid represents the earliest ocean.

There are a good many reasons for believing that the ocean has steadily accumulated salts. It now contains about thirty-five parts per thousand, or nearly five times the amount of concentration which the blood fluid exhibits and which was by our modified hypothesis the concentration of the ocean in Cambrian days. It is likely that life began at a higher temperature than 111° F., and when there was very little salt in the ocean at all. The water and the temperature may then have grown more favourable to the development of protoplasm and the life of the cell. As the ocean accumulated sodium and lime it grew more and more stimulating up to a point when it grew over-stimulating and poisonous. Up to that point there would have been no reason for the cells to accumulate lime; it would have suited them best to accept the stimulating and beneficial changes which were taking place in the medium where they lived and moved and had their being. But when the ocean, accumulating more lime, passed the point where it was the best place in existence for the open-bodied animals, the more vigorous of these would try to resist the disastrous effect of the change in various ways. They cut themselves off from it by membranes. They secreted a more or less impervious carapace or shell. They then got out of their too-stimulating surroundings altogether and migrated to the air, or to the land perhaps by way of shore sands or muds.

The period when the ocean seems to have passed its prime as the best receptacle for life may have been the Cambrian. After then there appeared numerous forms of life able to leave, as their predecessors had not been able to do, traces of their bodies in the rocks. Their predecessors had had no need for skin or shell. But once the skin and shell had been developed, their great advantages for other purposes of support and defence no doubt soon made themselves felt. We may conveniently sum up here, instead of in a later chapter, Dr. Lane's conclusions as to the conditions of the

ocean, when life first began in it. His factors are as follows :—

1. A warmer ocean, and consequent greater activity of life.

2. A constant approach of the ocean towards better conditions of life till early Palæozoic times. This caused the organisms not to cut themselves off from the ocean, but to remain open. Hard parts were rare and the living things were exposed throughout to the modifying effects of their surroundings.

3. Cumulative heredity was not then very strong in classifying the living things into strong well-marked types.

4. There were wide fields open to successfully modified forms of life, because there was not there the same keen struggle for existence or any rival form of life. Without many natural enemies one form of life could, therefore, multiply in great abundance.

5. The frequency of generation in the lower animals and plants was also a marked feature in the life of this era.

6. They may not have been such a marked flow and ebb of life in accord with the seasons.

7. While new forms of life (some inimical to others) were being developed a stimulus was thereby created to meet their new conditions.

Permanence of Fundamental Characters

We may add a few words in elaboration of the foregoing points. We have begun with a condition of things where single-celled organisms lived bathed in the primitive sea; we have assumed that they then became congeries of cells—multicellular—and that then among other structures they acquired a circulatory system. At first the fluid in this circulatory system was in open communication with the water of the sea; it was in fact modified sea water. We still find animals, cœlenterates, of this kind in the sea.

Then the circulatory system became shut off from the outside world and formed a closed system of canals. When this closure took place, the composition of the blood, as regards the relative proportions of the inorganic substances in it, was the same as that of the surrounding sea water.

But why, it may be asked, are we to assume that this liquid has remained unaltered in the animals which now carry it. The answer to that is, that the fundamental characters of living organisms change very slowly, though evolution alters so greatly their less fundamental aspects. Take the instance of protoplasm. Protoplasm is a mixture of immensely complicated substances.

It is almost infinitely variable in composition, as variable probably as the species of organisms which are based on it. Yet in spite of their variability we find it everywhere essentially the same in general characters and chemical properties—though there may be many different types of structure. If the protoplasm of both animal and vegetable cells is the same, then since these had a common ancestor, we seem justified in assuming that both animal and vegetable protoplasm is similar in structure, general composition and reaction, to the protoplasm of the ancient organisms from which both kingdoms were born.

Again when cells split up before reproducing themselves, the process, complicated as it is, is similar in animal and vegetable cells. That is another point to aid the assumption in favour of the continuity of the structure and reactions of protoplasm through all the ages.

And again—vertebrate animals, molluscs and crustacea all have skeletons composed of carbonate and phosphate of lime—not skeletons composed of silica or iron, or clayey matter. Why?—seeing that silicon and aluminium are more abundant in the Earth's crust than calcium. Hosts of organisms have siliceous skeletons though none has a skeleton in which the earthy basis is iron or aluminium.

The reason that the vertebrata contain lime as their basis, is evidently because when their ancestors lived in the sea the water of the sea contained a large proportion of calcium. For long ages these organisms therefore took lime from the sea: and so a "lime habit" became established. These ancestors adjusted themselves to an environment where lime was a prominent factor; and heredity has stamped this adjustment on the living vertebrates which form their skeletons just as their Silurian forefathers did.

So just because the primitive single-celled organisms lived in a sea where the dissolved salts were present in certain proportions, their living substance came to contain these salts in the same relative proportions as did the sea water. Heredity fixed this proportion of the elements sodium, potassium, calcium, and magnesium in the protoplasm of the primitive organisms, and we see it to-day in the composition of the protoplasm of living animals.

Then multicellular organisms containing a liquid like that of the surrounding sea were developed: and when this circulatory system of liquid was shut off from the sea, it retained none the less the same composition. Heredity maintained the composition of the blood; and therefore the proportions of the salts of sodium, potassium, calcium, and magnesium in the blood of living vertebrate animals are the same as those of the sea in very remote geological times.

The Breathing of a Body of Water

When life appeared in the sea or in the waters which deepened into seas a new relation between the water and the atmosphere was established and maintained. All are familiar with the examples of animals which inspire oxygen and give out carbonic acid, or of plants which exchange carbonic acid for oxygen. A body of water which contains animal and vegetable life is a breathing apparatus which is continually exchanging gases with the atmosphere.

For the sake of simplicity we may consider first the instance of an inland lake. A lake can be aptly compared with the blood of one of the higher animals, which consists of fluid and a number of living cells within it. The living cells in the lake's fluid are the animals and vegetables that find a tenancy there. The respiration of the lake, like that of the higher animals, may be divided into external and internal respiration. By the external respiration we mean the absorption of certain gases from the air and the return of other gases to it, as well as the processes by which the exchange is brought about. By the internal respiration we mean the gaseous changes which take place in the lake itself, between its various plants and animals and the water surrounding them. With these exchanges came the chemical processes by which the gases are altered or new gases are made in the course of the vital processes of the dwellers in the lake.

The external respiration of a lake closely resembles that of a living thing. The lake absorbs oxygen, carbonic acid, and nitrogen from the atmosphere; and returns to it nitrogen, carbonic acid, and sometimes other gases. The nitrogen absorbed by a lake, like that taken in by an animal, has little to do with the vital processes. In autumn as the lake cools, larger amounts of nitrogen are absorbed. In summer, as the lake warms and the capacity of the water for holding gases in absorption becomes smaller, some of the nitrogen is lost. This process is a purely physical one and has apparently no influence on the life of any of the organisms whose home is in the water.

But the respiration of oxygen is a different matter; and is of the first importance to the living things of the lake. Speaking roughly, we might say that an inland lake was an organism which took one full breath in the autumn, and another less deep in the spring; in the winter it does not breathe and in the summer it breathes very lightly. As the lake cools in autumn its temperature gradually becomes

the same from top to bottom; and when its temperature has become uniform the wind that plays over its surface comes into contact with every part of it, because the waters turn so readily over and over, no stratum of that having reason to remain below another. As a result inland lakes, even those which are as much as two hundred feet in depth, become saturated with oxygen at a temperature a little above the freezing-point. The quantity of oxygen may be about one per cent by volume; nearly twice as much as the water will hold at the high summer temperature. In this condition the lake goes into winter quarters: and perhaps becoming covered with ice is shut off from direct connexion with the atmosphere. During this period the stock of oxygen is used up to some extent, especially near the bottom: but the vital processes of the life-forms situated there go on slowly. Exceptions sometimes occur in shallow ponds where the oxygen may become altogether used up.

Associated with this partial consumption of the oxygen there is an increase during the winter of carbonic acid gas, the main gaseous product of respiration: and the quantity of it may become considerable. In the spring the water of the lake again becomes uniform in temperature; the carbonic acid becomes used up by the springing plants: and again the wind turns over the waters of the lake and treats them with oxygen. But as the temperature in spring is higher than in autumn, the amount of oxygen taken in is less. The rising temperature of the water continues to diminish the quantity of it: and as summer draws near another cause of expulsion comes into play. The surface water acquires a higher temperature than that at the bottom; and the warmer water being lighter stays at the top, so that it becomes increasingly difficult for the wind to create and maintain a complete circulation of the water. Thus the lower levels are put at a disadvantage in securing new supplies of oxygen from the air.

From the point of view of the comparison with an animal, a lake is at a grave disadvantage in acquiring oxygen from the air. In a large animal there are elaborate provisions for the absorption of oxygen from the air and its distribution within the animal. In man, for example, the absorbing surface of the lungs is about 2000 square feet, an area as great as that of the surfaces of a room twenty feet square and fifteen feet high; and there are specific chemical substances in the blood, such as hæmoglobin, which take up the oxygen with strong affinity. But a lake has only its surface, which may be extremely small in comparison with its mass; and it has no chemical constituents with an affinity for oxygen. Its circulatory processes, again, are sluggish indeed when compared with those of an animal, and the methods of distributing the oxygen consist merely of diffusion: of wind mixing and of current conveyance.

Internal Respiration of a Lake

There remains the internal respiration of the lake, or the interchange of gases among its population of organisms. But we touch on this question merely to note its difficulties. It is said that no branch of animal physiology is more intricate and more less understood than that of internal respiration. This is true also of the internal respiration of the lake. From its waters living things are drawing supplies of gas, each after its kind, and to the water each is contributing gases differing in amount and composition. Animals are withdrawing oxygen from the water and giving carbonic acid to it. Algæ are repeating this process by night and reversing it by day. Fungi and bacteria are using oxygen in the course of their internal vital activities; they are employing far larger quantities in the fermentative processes which they maintain. Innumerable chemical changes comprised in decomposition and fermentation, going

on under all sorts of conditions, are adding to the water gases of different kinds and in varying proportions. "It is impossible," says Prof. E. A. Birge[1] "even to attempt a picture of the internal respiration, with its countless operations each adding to or subtracting from the sum of gases in an intricate network of processes connected by rotations which cross and interlock at a thousand points." To mention only two—there is the manufacture of oxygen (considerable in lakes containing an abundance of algæ) and the demand for carbonic acid gas. Carbonic acid gas exists in the air in a small amount, four parts in 10,000: but small as the quantity is the land plants are able to take from it ample supplies of carbon. But the lake plants are in different case; they must secure through a middleman, the water. The middleman may serve them so badly that the lake may have to depend on its internal resources for a supply of this food. The resources are considerable, for great amounts of the gas are manufactured in the lake and may be used as food of the green plants; and then there is a sort of internal circulation of carbonic acid. But the same poor conditions of transport which make it difficult for the oxygen to reach the lower levels of the lake, make the transfer of the carbonic acid to upper regions when it is required equally unsatisfactory. We see, therefore, why life is relatively so abundant in large and shallow lakes in which the circulating apparatus is at its best.

The problems of life and growth lightly sketched in the foregoing passages are of still greater complexity in the sea. The complexity is increased by the presence of calcium and magnesium and other salts in solution; and by the immensely greater range of the factors of density, pressure, and temperature in the oceans. But the smaller sketch, if it is

[1] "Presidential Address to the American Fisheries Society," July 1907.

extremely inadequate as a representation of conditions in the sea, may serve as an indication of some of the relations between sea and atmosphere, and may suggest some of the interchanges which from the earliest epochs have existed between them.

CHAPTER X

THE BEGINNINGS OF LIFE

Evolution of organic from inorganic matter—Loeb's experiments—Spontaneous generation—Cosmic germs—Weismann and the origin of life—Simplest forms of life—Origin of land plants.

THE appearance of life on the Earth modified many of the processes of rock formation. It altered, or helped to alter, the character of the waters; when it emerged from the waters it modified the character of the land surfaces; and it was destined in many ways to be a principal agent in building up strata. From a geologically-historical standpoint it is interesting as marking the epoch at which the temperature, atmosphere, and moisture of the planet were such as to permit the development of protoplasm. Of the conditions under which its earliest existence became possible or of the causes which produced it, there is no information. The views of those who regard organic life as merely a step in the evolution of all matter, inorganic or organic, are well known, and need only brief reference here. They have never been better expressed than by Prof. Huxley more than forty years ago:—[1]

"But it will be observed that the existence of the matter of life depends on the pre-existence of certain compounds, namely, carbonic acid, water, and ammonia, and withdraw any one of them from the world and all vital phenomena come to an end. They are related to the protoplasm

[1] "The Physical Basis of Life," "Fortnightly Review," reprinted in "Collected Essays," February, 1869.

of the plant, as the protoplasm of the plant is to that of the animal. Carbon, hydrogen, oxygen, and nitrogen are all lifeless bodies. Of these, carbon and oxygen unite in certain proportions and under certain conditions to produce carbonic acid; hydrogen and oxygen produce water; nitrogen and hydrogen give rise to ammonia. These new compounds, like the elementary bodies of which they are composed, are lifeless. But when they are brought together under certain conditions they give rise to the more complex body, protoplasm; and this protoplasm exhibits the phenomena of life."

Prof. Huxley adds that he sees no break in this series of steps in molecular complication and he is unable to understand why the language which is applicable to any one term of the series (such as carbonic acid) may not be applied to any of the others (such as protein or such as protoplasm). We think fit to call different kinds of matter carbon, oxygen, hydrogen and nitrogen and to speak of the various powers and activities of those substances as the properties of the matter of which they are composed.

"When hydrogen and oxygen are mixed in certain proportions and an electric spark is passed through them they disappear and a quantity of water, equal in weight to the sum of their weights, appears in their place. There is not the slightest parity between the passive and active powers of the water and those of the oxygen and hydrogen which have given rise to it. At 32° F. and for hundreds of degrees below that temperature, oxygen and hydrogen are elastic gaseous bodies, whose particles tend to rush away from one another with great speed. Water at the same temperature is a solid whose particles tend to cohere into definite geometrical shapes. Nevertheless we call these and many other phenomena, the properties of water, and we do not hesitate to believe that in some way or another they result from the properties of the component elements of the water. We do not assume that a something called 'aquosity'

entered into and took possession of the oxide of hydrogen as soon as it was formed and then guided the aqueous particles to their places in the facets of the crystal, or among the leaflets of the hoar frost.

"Is the case in any way changed when carbonic acid, water, and ammonia disappear, and in their place, *under the influence of pre-existing protoplasm*, an equivalent weight of the matter of life makes its appearance.

"It is true that there is no sort of parity between properties of the components and the properties of the resultant. But neither was there in the case of water. It is also true that the *influence of pre-existing protoplasm* is something quite unintelligible. But does anyone quite comprehend the *modus operandi* of an electric spark, which traverses a mixture of oxygen and hydrogen? What justification is there, then, for the assumption of the existence in the living matter of a something which has no representative or correlative in the non-living matter which gave rise to it?"

Since Huxley wrote this passage, the study of the atom and of electricity has led to the belief that the elements themselves are not immutable and that matter and energy are interchangeable terms. If it was possible for Huxley to believe that living protoplasm was but an association of the elements in just proportions—without any interpolation of a "principle of life"—it should be easier now to believe that life consists merely in a right co-ordination of the energies and substances of the elements. But the fact remains that though more than a generation has elapsed since Huxley's words were written, biological research is no nearer a plausible demonstration of the causes of life than heretofore. Knowledge and theory are still bound by his parenthesis that life can only appear *under the influence of pre-existing protoplasm.* In other words, that unless life already exists, new life cannot be evoked.

Loeb's Experiments

The nearest approach to a modification of this proposition arises from the experiments of Prof. Jacques Loeb and of some Russian biologists. Loeb has succeeded in inciting the eggs of a sea-urchin to development by chemically stimulating them. In an address delivered at the Seventh International Zoological Congress (Boston, 1907) he summarized the various methods by which larvæ were produced from the unfertilized eggs of sea-urchins. The method consisted partly in changing the density of the sea-water in which the eggs existed, partly in supplying the water with a new fatty acid. Loeb's conclusions, broadly stated, are that these artificial methods imitate the action which ordinarily the fertilizing sperm cell sets up when joined to the egg-cell. This action he regards as that of merely setting in motion the chemical activities of the nucleus of the egg-cell and of guiding it in the right direction. When an egg-cell exhibits the first indications of what we may call birth, its nucleus develops, enlarges, and begins to show signs of splitting up. Loeb regards the nucleus as one of those substances which chemists have called catalysts or catalyzers.

There exist a number of substances known to chemists, the mere presence of which in the presence of other bodies appears to exercise a commanding influence on such bodies, albeit the "catalyzing" substances themselves remain apparently unaffected in bulk or chemical constitution. A trace of a catalyzer will bring about the chemical transformation of enormously large quantities of other substances which lie in its presence. Thus a solution of hydrogen peroxide, the substance so famous for bleaching purposes, will if left alone very slowly separate into oxygen and hydrogen. But add to it a trace of colloidal platinum, so finely divided that the platinum is not the $\frac{1}{300,000,000}$th

part of the bulk of the liquid, and the breakdown will take place at once. Inorganic substances are not the only catalyzers. Many living organisms have the same power. Thus a drop of blood added to the hydrogen peroxide would bring about the same action, and it would be due to the presence of a catalyzing agent in the blood which is called "hæmase". Similarly "diastase" transforms starch into sugar. Loeb, as we have said, regards the nucleus of the egg-cell as having the properties of a catalyzer and he believes that by appropriate chemical additions, this catalyzer can be awakened to activity. But though a chemical agent can thus apparently be made to fulfil *one of the functions* of the sperm cell which marries the egg-cell, the process and its results are far from complete; and Prof. Loeb is far from being dogmatic on the point of ever being able to produce living matter from inanimate.

Spontaneous Generation

In short, the precise conditions under which life can begin *de novo*, or under which it was born, have not been stated; though it seems reasonable to suppose that if life is chemical in origin it is as likely to be born anew out of inaminate matter now, as at any other period in the world's history. This position is clearly stated in Dr. Charlton Bastian's "The Nature and Origin of Living Matter" (1905): "To assume that the natural origin of living matter took place once only in the remote past, and that it has not been repeated, or if repeated in past times, that it no longer goes on, is to look upon this process as a kind of natural miracle, and to postulate a break in continuity which ought only to be possible in the face of overwhelming evidence of its reality. . . . For living matter to have come into being in the remote geological past, when nothing of the kind existed, must have been a far more difficult thing than for it to arise *de novo* now, and during the past ages, after living

things had been plentiful on the face of the Earth.[1] Originally there would have been no organic compounds on the waters, diffused from pre-existing living things such as commonly exist at the present day—matter of this sort would itself have had to come into being by natural agencies before the next step in complication would occur: that is, the formation of living matter itself."

We have quoted Dr. Bastian, in spite of the recognized heterodoxy of many of his views concerning the origins of life, because he is one of the ablest defenders of the continuance of archebiosis. He adds: "When it is said that a belief in spontaneous generation (archebiosis) would tend to contradict the experience of all mankind—inasmuch as we are accustomed to see living things invariably proceed or take their origin from other living things—my reply is that archebiosis may be occurring all round us, and that from its very nature it must be a process lying altogether outside human experience—and never likely to come within the actual ken of man". In other words, the beginnings of life are ultra-microscopic: and no vision will ever reveal their chemical or physical determinants.

Cosmic Germs

That is perhaps the least assailable position which the biologist can take up with regard to the earliest beginnings of life on a planet; and it will at any rate save him from the speculation to which Lord Kelvin once acted as a kind of sponsor,[2] and which has more lately been favoured by

[1] Mention should, however, be made of the alternative view to which physiologists like Verworn and Preyer have given some kind of authority. According to this view the essentially active principle of living matter is a radicle of cyanogen, a compound of nitrogen and carbon which is produced only at great heat. Cyanic substances may have existed in greater quantity when the Earth was hotter.

[2] By an incidental reference to it from the Presidential Chair of the British Association in 1871.

Prof. Arrhenius, that life came from some other locality in the universe to our own planet. A question which naturally follows on the supposition that such life germs exist elsewhere in space takes the form of asking how they could come to this planet; and how they could survive the journey.

Prof. Arrhenius has sought to make the theory more plausible by introducing considerations relating to the life of spores under conditions of extreme cold; and also to the pressure of radiation. There are many phenomena which are explained by supposing that radiation from a bright body (the Sun for example) exerts a definite pressure. The pressure of the Sun's light on the Earth has been calculated by Prof. Poynting at 75,000 tons. The pressure of this light diminishes the pull of the Sun due to gravity by one-forty-billionth only and is therefore negligible. But the pressure of light on the small bodies, the cosmic dust, which float about the solar system is not negligible. If a sphere be supposed to exist which was only one-forty-billionth of the Earth's diameter, and was in fact not greatly removed from the size of a molecule, then the light pressure on it would be equal to the gravitational pull.

Translate these considerations into the possible instances of cosmic dust floating through space, and it does not seem altogether chimerical that a speck of dust containing the germ of life might be expelled from some other planet, or even from some other solar system than our own, and yet be carried to this planet, or to this solar system. Could such a germ survive its experiences of temperature, or the length of its journey? To these queries Prof. Arrhenius [1] responds that some germs of life, staphylococci, have been subjected to temperatures of liquid air (195° C. below freezing) for several months and have retained their vitality. The cold of space

[1] "The Life of the Universe," Vol. II, pp. 254-5, translated by Dr. Barms (Harpers), 1909.

is not much more intense than this. So it is at any rate conceivable that life might be conveyed from planet to planet and yet survive some of its probable experiences. It has been doubted however whether germs of any kind could survive the ultra violet rays which traverse space.

The immigration hypothesis, however, as Miss Agnes Clerke remarked, even if it were plausible could not be made useful. Difficulties do not vanish on being pushed into a corner: the problem of life is as formidable in one world as in another.

Weissmann's Commentary

Weissmann,[1] who confesses that he sees no escape from the assumption of spontaneous generation in the planet, points out that all attempts to discover the conditions under which spontaneous generation took place must nevertheless be unsuccessful. That is because not only are we unlikely to be able to reproduce the exact conditions, but even if we did the resultant germ of life arising from what we suppose, by hypothesis, to be the requisite chemical and physical combinations, would be invisible. Weissmann arrives at the conclusion that minute living organisms, "biophors," or "life bearers" as he calls them, form the basis of all organisms —but these "biophoridæ," which are the only units that could possibly be supposed to arise spontaneously out of inorganic matter, "are so extremely far below the limits of visibility that there is no hope of our ever being able to perceive them . . . even if we should succeed in producing them". Weissmann continues:—

"The question as to the 'where' of spontaneous generation must also be left without any definite answer. Some have supposed that life began in the depths of the sea, others on the shore, and others in the air. But who is to

[1] "The Evolution Theory," by A. Weissmann (translated by J. A. Thomson Arnold (1904), Vol. II, pp. 366, 371, 410.

divine this when we cannot even name theoretically the conditions and the materials out of which albuminoid-like substances might be built up in the laboratory. Nageli's hypothesis still seems to me to have the greatest probability. According to his theory the first living particles originated not in a free mass of water, but in the superficial layer of a fine porous substance like clay or sand, where the molecules of solid, fluid, and gaseous bodies were able to co-oporate.

"Only so much is certain, that wherever life may first have arisen upon this earth, it can have done so only in the form of the very simple and very minute vital units which even now we only *infer* to be parts of the living body, but which must at first have arisen as independent organisms." (These independent organisms Weissmann calls biophors, or collectively, the biophoridæ.) As these possessed the characters of "life," they must have possessed above all the capacity of assimilating in the sense in which the plants assimilate, that is, of renewing their bodily substance continually from inorganic substances: and the capacity of growing: and of reproducing. The first advance to a higher stage of life must have been brought about by multiplication; accumulations of biophoridæ would be formed.

In this way the threshold of microscopical visibility would be crossed: but long before that time a differentiation of the biophors, on the principle of division of labour, would have taken place within the colonies of biophoridæ. This first step towards higher organization must probably have taken enormous periods of time: for before any differentiation could occur and bring any advantage to these units of life the masses of them must have become orderly, and have formed themselves into a strong association with definite form and definite structure. Only then was the further step made of a differentiation of the individual biophors forming the colony. . . . These differentiated colonies bring us nearer to the lowest known organisms,

among which are some whose existence can only be inferred.

Bacteriologists call some of the smaller indistinguishable organisms "filter passers," because the finest laboratory filters cannot detain them: and they have never been seen. The bacillus of swine fever, hay cholera, and possibly of fowl diphtheria are suspected of being invisible filter passers: and there are several human diseases which are attributed to similarly minute and invisible organisms.

The invisible organisms have been called "monerons," and it is assumed that they have no nucleus. These non-nucleated monerons bridge the way to the formation of nuclei, and when once the state of nucleus formation is reached, life has arrived at the stage of the cell. The nucleus, according to Weissmann's view, is primarily a storehouse of "primary constituents"; and its origin must have begun at the time when the cell body reached a stage when it had so much and such varied things for its different parts to do, that mere splitting into half would not serve—it was necessary that each half should take with it a reserve fund from the "storehouse of primary constituents".

Simplest Forms of Life

However, we need not follow this differentiation out more closely. Let us think, with Weissmann, of the simplest microscopic monera on the mud of the sea-coast, equipped with the faculty of plant-like assimilation. We shall see that the unlimited multiplication of these organisms would cause differences in nutrition, for those lying uppermost would be in a stronger light than those below, and would, therefore, be better nourished, and consequently would transmit the variations thus caused to their progeny. Thus it is conceivable that even the more or less favourable position as regards light would bring about the origin of two different races from the same parent form. As it is conceiv-

able in the case of light, so is it also in regard to all the influences which cause variation in the organisms.

The problem of the nature of the first living things lies, then, far beyond any possibility of observation. The oldest and deepest geological strata in which fossils can be found contains animals of such a relatively high state of organization that they certainly must have had a very long series of ancestors behind them. The whole of the roots of their genealogical tree lies buried in rocks whose very nature has been altered and disorganized by enormous pressures and probably high temperatures. We cannot do better than quote at this point Sir E. Ray Lankester's observations[1] on the hypothetical first forms of life:—

"What was the nature of the first protoplasm which was evolved from not-living matter on the Earth's surface? Was that first protoplasm most like animal or most like vegetable protoplasm as we know it to-day? By what steps was it brought into existence?

"Briefly stated, the present writer's view is that the earliest protoplasm did *not* possess chlorophyll, and therefore did not possess the power of feeding on carbonic acid. A conceivable state of things is that a vast amount of albuminoids and other such compounds had been brought into existence by these processes which culminated in the development of the first protoplasm, and it seems likely enough that the first protoplasm fed on these antecedent steps in its own evolution, just as animals feed on organic compounds of the present day—more especially as the large creeping plasmodia of some Mycetozoa feed on vegetable refuse. It indeed seems not at all improbable that . . . the Mycetozoa represent more closely than any other living forms the original ancestors of the whole organic world.

[1] "Protozoa," by E. Ray Lankester, "Encyclopædia Britannica" (6th edition). See also "A Treatise on Zoology," Part I, "Protozoa" by E. Ray Lankester, Introduction, p. xv.

"At subsequent stages in the history of this archaic living matter chlorophyll was evolved and the power of taking carbon from carbonic acid. The "green" plants were rendered possible by the evolution of chlorophyll but through what ancestral forms they took their origin, or whether more than once—i.e. by more than one branch—it is difficult even to guess.

"The Green Flagellate Protozoa (Volvocineæ) certainly furnish a connecting point by which it is possible to link on the pedigree of the green plants to the primitive protoplasm. It is noteworthy that they are not very primitive, and are indeed highly specialized forms as compared with the naked protoplasm of the Mycetozoon's plasmodium.

"Then we are led to entertain the paradox that though the animal is dependent on the plant for its food, yet the animal preceded the plant in evolution."

An example of the difficulties in dealing with the first steps in the establishment of life on the Earth is disclosed by the publication in 1908 of Bower's treatise on the origin of land plants.[1]

ORIGIN OF LAND PLANTS

Prof. Bower's treatise is based on the views which he has long held on the alternations of generations in land plants. In the examination of the causes of these alternations he discovers a possible mode of their origin, and on it founds a theory of the circumstances of the first emergence of plants from the sea. Broadly stated, Prof. Bower's view is that the land plant emerged from the sea as a simple thallus bearing an egg-cell. This, on fertilization, instead of giving rise at once to a new sexual person produced a vegetative growth which ended with the production of non-sexual spores. The vegetative structure thus intercalated (by an elaboration of

[1] "The Origin of a Land Flora," by F. O. Bower, F.R.S. (1908).

the egg-cell) became the second generation of the plant (sporophyte).

The sexless sporophyte conquered the dry land: the sexual phase, the gametophyte, with its conservative adherence to traditional methods, remained dependent on a more or less watery environment until such time as the seed plants came to be developed. Then the prothallus became a mere parasite on the sporophyte enclosed within the megasporangium, so that fertilization could take place in the plant itself. . . . Such is the theory in very imperfect and brief outline. But it has been assailed by botanists, who maintain that the belief in a distinct and separate origin for the two generations in the life-cycle of plants cannot be maintained, and a great deal of recent work (by Lloyd Williams and others) favours the idea that there was no introduction of any new phase into the life-cycle of plants, but that the alternating generations of plants arose by the modification of homologous individual plants. The subject is of too abstruse a character for exhaustion in a general summary: but the difficulty of forming generalisations of the kind will be thereby exhibited. The object of the foregoing chapter is not to pronounce on these rival theories, but partially to indicate the chasm which lies between inorganic and organic development in the planet.

CHAPTER XI

AGENCIES AT WORK

Atmospheric circulation—Transportation of dust—Atmospheric erosion and sand dunes—Rain—Work of running water—Work of the sea—Underground waters.

FROM this point onwards the planet may be considered as a body in which all the agencies which are at present altering its surface or its constitution were at work —air, water, heat external and internal. The first two of these agents may be regarded as the more important in the mason's work of laying down the strata of the Earth's surface; to the last named may be allotted the part of altering and disposing them. Or, to vary the metaphor, air and water made the bricks of the planet's crust; and heat fired them.

In the history of warfare advance has always been in the direction of mobility; swiftness of movement has more than compensated for the diminishing weight of equipment. The comparison indicates why it is that the insubstantial atmosphere has had an important share in moulding the planet's history—it has great mobility and great chemical activity. Incidentally its presence helped the work of the Sun and was allied to the work of water in producing rain and dew and in fostering vegetation. The first activity of the atmosphere is in producing the mechanical effects of the transportation of dust. The explosion of Krakatoa in 1893 furnished a striking piece of evidence of the way in which the atmosphere at great heights may be charged with dust; and

though the presence of dust at such levels in this instance was so exceptional, yet in greater or less quantity dust is always being carried upwards. The study of the atmosphere by means of kites and balloons has disclosed many unsuspected facts concerning its strata and movements. Dr. W. N. Shaw, of the Meteorological Office, has compared its strata to the coats of an onion: and Mr. Lawrence Rotch has shown that in whatever region of the Earth the atmosphere is examined there will occur, at a height of several miles, a layer, called the "reversing layer," where temperature ceases to fall with increasing height. This is not the only reversal of conditions occurring in the atmosphere. At varying heights the surface winds are replaced by steady seasonal currents of air; and these again are probably subsidiary to a general circulation of the atmosphere due to the combined effects of the Sun's heat and the Earth's rotation. A planet which is rotating and which is enveloped by an atmosphere carries its atmosphere with it: but it is not certain whether, or to what extent, the atmosphere slips as the planet rotates; and the effect of the Sun's heat in disturbing the circulation of the atmospheric envelope adds another factor to a problem as yet incompletely understood.[1]

[1] "It is true that much remains to be done in working out the details of the subject; but the main principles admit of very simple expression. Briefly the variations in atmospheric pressure on the Earth's surface are dependent on differences of temperature, moisture, and centrifugal force—to use a useful term by no means free from objection but sufficiently well understood. The tendency of heat alone would be to make the pressure increase continuously from the equator to the poles. That of centrifugal force alone has exactly the contrary effect, for air moving towards the poles has a greater rotational velocity than that proper to its new latitude, and therefore tends to rise, while air moving towards the equator tends to sink. The magnitude of this effect is dependent on the rate of change in the length of the radius of rotation, a rate which increases rapidly as the pole is approached. Thus it comes about that while the influence of heat difference is greater in low latitudes that of difference of centrifrugal force is more powerful in high latitudes. If then the Earth were a uniform solid spheroid, there would be a belt of low pressure round the equator and two areas of low pressure at the poles with high

TRANSPORTATION OF DUST

Few of the Earth's winds can be horizontal: most have an inclination upwards or downwards; and there are reasons for believing that the air, when it is heated by the surface, does not rise in broad sheets but in spirals, or air-spouts of greater or less force. On these spirals the dust is carried upwards and transported by the upper currents to great distances. There is hardly any snow field so high that it does not carry on it evidences of dust which has been thither transported.

Nor must the ability of the wind to transport life, together with the dust, be forgotten. Mr. E. M. Kindle, of the U.S. Geological Survey, noticed in the breaking ice-pack of the Behring Sea a large number of the ice-cakes discoloured by dirt or dust. The very fine texture of the dust suggested that most of it reached the surface of the ice through transportation by the wind. This fine material gathered itself into little pellets as the melting of the ice and snow proceeded. The colour of the dust was grey, black and brown, and the black dust was unquestionably of volcanic origin. But the most interesting feature of this ice-borne dust was the presence of marine diatoms in nearly all the samples. These organisms were quite as abundant in the dust samples of volcanic origin as in the grey non-volcanic dust. In this connexion we may recall the fact that though the Krakatoa explosion reduced the island to a heap of glowing ashes, it

pressure belts between. In the colder regions, however, the air over the open sea is as a rule warmer as well as moister than that over ice or land masses. Tracts of open sea in high latitudes are therefore characterised by abnormally low pressure. Accordingly we find in the North Atlantic and Pacific two areas of low pressure imposed upon the regular decrease of pressure from the lower latitudes to the North Pole itself. Similarly in the southern hemisphere the open circum-Antarctic sea gives rise to a circle of abnormally low pressure. Beyond, in the region of Antarctic land and ice the pressure is probably somewhat higher, representing the normal low pressure of the pole" (J. W. Evans, "Science Progress," December, 1908).

is now covered on one side with vegetation. It has been suggested that the first steps to re-clothing it with life were taken by the breaking up of the rock-silicates of the micro-organisms of the soil. The subsequent vegetative developments were due to seeds and spores, either wind-borne or water-borne.

It has been remarked that while it would perhaps be an exaggeration to say that every square mile of the Earth's land surface contains particles of dust brought to it by the winds from every other square mile, yet such a statement is not very wide of the mark. There are many examples of extensive deposits of dust. In China there is an extensive earthy formation, the *loess*, sometimes reaching 1000 feet in thickness, which some geologists believe to have been deposited by the wind, and although this conclusion has been disputed, the *loess* of other regions is certainly wind borne. In various parts of Kansas and Nebraska there are considerable beds of volcanic dust, sometimes thirty feet in thickness, which must have been transported thither by the wind though there are no known points of volcanic action, either past or present, within some hundreds of miles of the localities where the dust occurs. Much of the dust transported by the wind is carried away over seas or lakes and falls into them. By this means sediments are furnished which collect at the bottoms of seas and lakes. There is no means of determining the amount of dust blown into the sea: but probably if such determinations were possible, the result stated in weight would be surprising. Sir Thiselton Dyer, after a fog which occurred in London at Christmas some years ago, had the three acres of glass which house the plants at Kew scraped and cleaned. He derived thence six tons of smoky dust. If London fogs can do that with carbon particles, what weight of tons to the acre would not the floor of the sea accumulate in the course of centuries from particles of other kinds of dust. The black and red

rains or snow which sometimes fall, and which have been noted in the British Isles and among the Swiss mountains, sometimes owe their colour to transported dust; and rain-dust of this kind in the south of England has been shown very plausibly to have been derived from African sand-storms or dust storms.

Atmospheric Erosion

The chief work of the atmosphere, however, is in altering the features of localities where it has dust or sand already to work on. Sand dunes, which are found all over the world from Southport to the Sahara, and from the coasts of Belgium to those of Lake Michigan, are the most familiar examples of this kind of atmospheric architecture. Once the winds have laid the foundation of a sand dune, it grows by what it feeds on: and offers a lodgment for ever-increasing quantities of sand. Dunes are sometimes 200 feet or 300 feet high, though they are commonly hardly more than a tenth of that height. The limit differs under different conditions. The wind's velocity is lower at the lower levels, and as a dune is built up a height is presently reached where the stronger upper winds sweep away as much sand as is brought to the top. The approximately equal heights of the crests of many dune ridges are to be accounted for in this way. Dunes may assume the form of hillocks or ridges. Both forms are found in the Sahara where possibly sand dunes reach their highest stage of development. Dune ridges are sometimes met with there which are so high and steep that they cannot conveniently be ascended and travellers have to make their way miles along their bases in order to find a break where the dune might be crossed. The wind-blown sand does not always take the form of dunes: but its massing is sometimes even more impressive. Lyell in his "Principles of Geology" noted that "innumerable towns and cities have been buried to the westward of the Nile,

between the Temple of Jupiter Ammon and Nubia . . . and . . . the sand which surrounded and filled the great Temple of Ipsambul first discovered by Burchhardt, and afterwards partially uncovered by Belzoni and Beechey, was so fine as to resemble a fluid while in motion. . . . The burying of several towns and villages in England and France by blown sand is on record; thus for example in Suffolk in the year 1688, part of Downham was overwhelmed by sands which had broken loose about one hundred years before from a warren five miles to the south-west. This sand had in the course of a century, travelled five miles and covered more than a thousand acres of land."

Dunes themselves may migrate, induced thereto by the continual transfer of sand from their windward to their leeward side. A remarkable instance of the migration of a sand dune[1] is recorded on the Kurische Nehrung on the north coast of Germany. The Nehrung is a long narrow neck of land, composed of sand lying off the main coast. A hundred years ago there was a big dune ridge across one side. It has migrated right across a church situated on the middle of the neck of land. In 1809 the dune was westward of the church; in 1839 it had shifted to leeward far enough to bury the church; in 1869 its migration had proceeded so far that the church was again disclosed. When dunes migrate into a timbered region they bury the trees and kill the forest. On the northern coast of Germany a pine forest of several hundreds of acres was thus destroyed in twenty years; and the migration of the dune beyond the forest leaves only devastation behind. We are considering here only the effects of wind-blown sand when left to the undisturbed forces of Nature: but Nature, which sometimes checks the progress of a dune by clothing it with a mantle of hardy binding vegetation, has shown mankind a way of

[1] Quoted by Chamberlin and Salisbury from Credner, "Elemente der Geologie".

dealing with these destructive agencies. The scientific study of sand dunes has revealed the laws to which they are obedient, and shown how the wind may build them and unbuild them. Off the Belgian, and Baltic coasts, and more recently in inland regions of the North American continent, steps have been taken by building timbered fences, wind-boards, and sheltering jetties to alter the distribution and formation of sand dunes and even to make them self-destructive. Leaving, however, these considerations we need only remark that dunes are likely to be found wherever sand is exposed to the wind, along the dry and sandy shores of lakes and seas, sandy valleys, and dry sandy plains. Along coasts they will usually be chiefly found only when the prevailing winds are off the sea or lake. In shallow water a reef may be built by the water and may rise above its levels. When the water subsides the sand dries and heaps itself up into dunes. Thus a process of "reclamation" from the sea may be set in motion by natural causes.

The effect of the wind on rocky surfaces would be inconsiderable were it not for the sand and dust which it carries. The work it may do when equipped with this implement of erosion may be comprehended by reference to the artificial sand-blasts which are used for etching glass and sometimes for cleansing or abrading the surfaces of stone-work. Rock surfaces, especially of sandstone, or when the rock is made up of layers of unequal hardness, are often carved by the wind-carried sand in very striking fashion. The erosion, therefore, is of three kinds. The winds pick up the fragments of loose surfaces and thus wear down the surfaces; the materials thus picked up wear the rock surfaces against which they are blown: and the sand itself suffers reduction in transit. These agencies are always insidiously at work; and when stimulated by violent atmospheric disturbances the change they bring about may be very great. Devastating cyclones are not familiar occurrences in Europe; but

even in Scotland the whole wood of Drumlanrig was overset by the wind in 1756; and about a century earlier the overthrow of a forest near Lochbroom in Ross-shire gave rise to a great moss where in less than half a century after the fall of the trees the inhabitants dug peat.

Even when the wind is still the atmosphere is silently at work; conserving the heat of the Sun's rays; aiding in the formation of dew and rain and hoar frost and snow; and thus promoting those various effects classed under the name of weathering. The sudden application of heat or cold to glass will crack it, and the variations of heat and cold to which rocks are exposed by day and night are slowly producing similar effects. If abundant moisture be present on the surface of the rocks then freezing and thawing will bring about these effects more rapidly. The effects have been called the "wedge-work" of ice. "The importance of this method of rock breaking," observes Prof. R. D. Salisbury, "has rarely been appreciated except by those who have worked in high and dry regions. Climbers of high mountains know that almost every high peak is broken rock to such an extent as to make its ascent dangerous to the uninitiated. High serrate peaks, especially of crystalline rock, are, as a rule, literally crumbling to pieces. The piles of debris which lie at the base of steep mountain slopes are often hundreds of feet in height and their materials are often in large parts the result of the process here under discussion. In mountain regions where atmospheric conditions favour sudden changes of temperature, the sharp reports of the disruption of rock masses are often heard. Masses of rock, even hundreds of pounds in weight, are frequently thus detached and started on their downward course. Livingstone reported that "the temperature of rock surfaces in Africa sometimes reaches 137° F. during the day and cools sufficiently at night to split off blocks 200 lb. in weight. . . . The disruption of rock by changes of temperature is not usually the

results of a single change of temperature, but rather of many successive expansions and contractions. . . . The sharp needle-like peaks which mark the summits of most high mountain ranges are largely developed by the process here outlined." Even in low latitudes and most climates the effects of temperature changes are often seen, especially in limestone regions.

Rain

But the atmosphere's chief activity is as a vehicle for water. The average amount of rainfall all over the world is variously estimated as somewhere between forty and sixty inches. The lower figure is at any rate within the mark. A good deal of this rain falls at high altitudes so that the work done in flowing back to the sea is great. If the water which falls on the land areas were never to run back to the sea, the oceans would be exhausted by evaporation in some 15,000 years. Another way of stating the work of evaporation is by estimating the force necessary to condense and diffuse the moisture which falls as rain and snow. The work done has been computed as the equivalent of a 300,000,000,000 horse power continually in operation. As the rain falls it takes from the atmosphere dust, seed spores and gases. Every rain drop that falls strikes a blow: and the cumulative effect of these immeasurable numbers of blows when extended over long periods of time, is not easily measured. When in addition the rain water contains acid gases the effect it produces is magnified—and though these effects belong rather to the work of running water than to that of the atmosphere, yet the atmosphere is the indispensable originator of them.

It is when the fallen rain has accumulated in rivers, lakes, underground waters, or has reverted to the sea that its chief work begins. It was from the first a very active agent in altering the face of the land. We may assume that there always was land, and that at no epoch in the

planet's history was the globe entirely covered by its oceans. It is nevertheless probable that most land areas have been at one time or other invaded by the sea. To this consideration another may be added—that many seas were once dry land. The ocean floor is not uniformly level; it has its mountains, its valleys, its ridges, as well as its plains and plateaus of grey ooze: but its chief characteristic when compared with the land is its flatness. What would be the character of a surface which slowly emerged from the sea, not by any volcanic uprising, but from the draining off of the waters? It would be a rather flat surface. It would be covered with sediments partly such as may have been washed there from the land; or which, first deposited by the wind as dust, had sunk beneath the waves; or such as consist of the powdered shells and skeletons of marine animals.

On such an area of uplifted sea bottom the winds and rains would immediately get to work. They would carve out gullies down which trickles would run to become streams as the gullies deepened into valleys; ridges and hills would arise from a process of exhaustion of the even surface; the stream, growing to a river and carrying mud and sand with it, would form new plains at a lower level than that from which it sprang. When in ages far removed the river has become an old one and the forces which uplifted the region whence it sprang have ceased to operate, the river's influence may be used to swing the scale back again, because of the depositions, drawn from the land, which it casts at its mouth into the sea.

Running Waters

It is usual to cite the sediments carried down by great rivers, such as the Amazon, the Mississippi, the Nile, the Irrawaddy and deposited in deltas where they discharged into the sea as examples of the work done by rivers: and the statistics are certainly impressive. For example, the

discharge of the Mississippi is nearly twenty billion cubic feet of water in a year and it carries with it 406,250,000 tons of solids. If all these solids were deposited within the City of London, everything therein would be buried some two hundred feet below the surface by the sediment. St Paul's Cross would not be visible after fourteen months' deposition. Rivers vary a great deal of course in the amount of sediment they deposit and the method of deposition. The Nile, for example, which drains an area almost equal to that drained by the Mississippi, does not deposit at its mouth one-seventh of the weight of sediment. The Irrawaddy, which is very nearly of the same rank of muddiness as the Mississippi, but drains only about one-tenth as many squares miles, deposits almost as considerable an amount of sediment at its mouth. If nine typical rivers be taken, the Potomac, Mississippi, Rio Grande, Uruguay, Rhone, Po, Danube, Nile, Irrawaddy, it is found that they bring down yearly from the lands they drain a layer of ·00614 of an inch. In other words, a typical river would lower the the height of the area it drains by some six inches in a thousand years. North America, it has been computed, is being lowered or degraded at the rate of one foot in 3500 years. If that rate were to continue, then in something like 7,000,000 years the whole continent would be reduced to sea-level. But this rate of degradation would not continue to the end, for as the continent became lower, the streams would become sluggish, and erosion less rapid. Long before the continent was worn flat the rate of lowering would become so slow that the time necessary to bring the continent to sea-level would be almost immeasurably prolonged. Furthermore, it is possible, as already has been seen, that the land may be subject to uplift, and if the rate of uplift were equal to the degradation the average height of the continent would not be affected.

Sir Archibald Geikie, in instancing some of the results

which arise from an arithmetical computation of the removal of land surface by rivers[1]—such as, for example, that if the whole of Europe were lowered at the same rate as the plain of Piedmont by the Po, it would be reduced to sea-level in half a million years—remarks that while these results are not strictly accurate they are not mere guesses. Attentively considered they suggest doubts as to the lengthy periods of time which are demanded by geologists for the accomplishment of many geological changes. The same authority furnishes another method of calculation. Taking the average rain-fall over the British Isles to be 36 in. a year, and its total volume to be some 68 cubic miles of water, he assumes that a fourth of it is returned to the sea by streams. If the muddiness be estimated at $\frac{1}{5000}$th of the volume of the water, we arrive at the conclusion that a foot of the British Isles is planed off every 8800 years. The mean height of the islands being estimated at 650 feet, they might be levelled in about five and a half million years. The loss from all portions of the land is not equal. The balance of loss must always be on the side of the sloping surfaces. In the case of a country where nine-tenths consists of comparatively level ground and one-tenth of steeper slopes, a foot of surface lost in 6000 years from the whole land is very differently apportioned. It amounts only to a loss of about 7 in. from the plains, but of about 5 feet from the valleys in the same space of time. Thus from the level lands a foot will not be removed in 10,000 years; but a foot will be worn out of the valleys in 1200 years, and a valley nearly a thousand feet deep may be excavated in a million years.

Work of the Sea

The sea is also a reduction agent of the land; but the spectacular effects which it produces, especially on the softer parts of a coast line, such as the east coast of England, or

[1] "Text Book of Geology" (4th ed. 1904), Vol. I, pp. 483-4.

the south coast of the Isle of Wight, have procured for its powers a higher estimate than they deserve; and these powers of erosion are in reality small when compared with those of rain and running water. If the rate of erosion by the sea be put at the comparatively high figure of ten feet a century, which is a high average, though on some coasts of course it is as easily surpassed as in others it is never approached, more than 50,000 years would be required to pare away a mile from a coast-line. In 5,000,000 years the sea eating its way thus into the Western coast of Europe, would have swallowed only a 100 mile strip. But the whole of Europe would have disappeared in that time were its surface lowered a foot in 6000 years by rainfall and running water.

Underground Waters

The evidence of the work of rainfall afforded by running surface water is not the only one. A great deal of the rain disappears beneath the surface where it continues to do the work of moulding the planet. The depth to which this ground water sinks has never been satisfactorily determined. No boring has yet reached a part where it seemed at all likely that the limiting depth to which water would sink had been reached. There is a popular belief that water sinks till it reaches such a temperature of heated rock that it is converted into steam. But it is not known at what depth below the surface water would be converted into steam. If, as there seems to be little doubt, the temperature of the Earth's interior rises with increasing depth, so beyond doubt does the pressure. Everyone is familiar with the fact that on the top of Mt. Blanc water boils at a lower temperature than at sea-level, because the atmospheric pressure is less. Many are also acquainted with one of the processes by which Sir James Dewar reached some of the critical boiling-points of liquid gases—by taking off the pressure from their surfaces by air pumps. Conversely if

the pressure on the surface of a liquid is increased it will have to be at a higher temperature than heretofore before it will boil.

The increase of temperature for depth varies a good deal in different parts of the Earth's surface, ranging from one degree for every 50 feet in the French collieries at Rouchamp to the one degree for every 125 feet in the Calumet and Hecla mine (U.S.A.). But taking an average increase of one degree for every 70 feet, the depth at which a boring would reach the ordinary boiling-point of water would be about 11,000 feet. Here, however, the pressure would not be by any means the same as at the Earth's surface. It would be equal to some 333 atmospheres to the square inch. But, as we have pointed out, the height to which the temperature must be raised in order to make water boil, increases with the pressure. Before a pressure of 333 atmospheres was reached; in fact when a pressure of 200 atmospheres was brought to bear on it, the water would refuse to boil. It is surmised that water may sink till it reaches the point where its critical temperature (the temperature at which water exists as a gas) is passed. This temperature, which is somewhere between 610° and 635° F., might be somewhere in the neighbourhood of 40,000 feet deep. Whether in these circumstances the *water-gas* would be absorbed by the surrounding rocks is not known: though some theorists, notably Prof. T. J. See, have assumed that this would be the case. But in any case we are free to assume that water in very large quantities is exercising, and always has exercised a considerable influence on the rocks of the crust for a depth of several miles below the surface. The freedom of its movements will be notably influenced by the porosity of the rock. Owing to pressure this will almost cease at considerable depths; so that the movement of the ground water is extremely slight in the lower part of the water-bearing rocks.

Near the surface the water moves freely; and its freedom of movement evidently depends on the porosity of the rock. This porosity diminishes with depth and of course differs greatly with the nature of the rock, sandstone, shale, granite, etc. If the average porosity of the whole six miles of crust in which water may be supposed to be held, were to be set down as between 2½ and 5 per cent—that is to say more porous than building granite but much less porous than building sandstone—then the water therein enclosed would form a layer between 800 and 1600 feet deep. This layer has been regarded as a watery sphere, like a shell enveloping the rocky sphere of the planet, and has been called the hydrosphere. The older geologists estimated its thickness and volume at much higher figures.

Some of the water thus sinking into the crust quickly returns, absorbed by plants; collected by wells or springs; joined to underground streams or rivers which ultimately join the sea. A small portion of the descending water finds its way into combination with the rocks. Some of it is restored by volcanoes and by volcanic vents—though the assumption that oceanic waters obtain access to the heated interior of the globe and there are absorbed into molten rock crucibles cannot be unreservedly accepted. Mr. Alfred Harker points out [1] that while water is present in all rocks that have been examined, yet "if we may speculate so far in the past history of the globe, it would seem not that the sea is the source of the volcanic water but that vulcanicity (in the broad sense of direct communication between the heated interior and the exterior of the globe) is the original source of the ocean's waters, and is slowly adding to them". It is at any rate probable that some of the water issuing from volcanoes and volcanic vents has never been at the surface before. It is possible that the supply of water from the inner rocks of the crust, where

[1] "The Natural History of Igneous Rocks."

the underground chemical laboratories are at work, may be equal to, or even greater than, the amount of water absorbed by the upper rocks.

The underground waters are continually effecting chemical and mechanical operations. Pure water will dissolve some minerals. Water that contains the carbonic acid extracted from the atmosphere or the products of decaying vegetable matter is much more efficient to dissolve minerals. Underground water may therefore be regarded as subtracting something from all the rocks with which it comes into contact, and from some subtracting a good deal. Or the flowing water charged with the mineral may leave some of it in exchange for another mineral which it extracts while pursuing its onward way; or, again, it may re-deposit its minerals without taking any toll. Lastly it may, as we have mentioned, enter into combination with a rock. New minerals may be thus formed, the pedigree of which may be so long and so complex as to be almost incomprehensible, but which are the descendants of rocky ancestors differing both chemically and physically from themselves. Here again statistics enable us to appreciate the great changes which may spring from causes which seem insignificant in themselves. The extent to which underground waters are charged with minerals in solution may be perceived by the deposits which they make. Even the Bath springs deposit each year enough mineral matter to make a Cleopatra's needle; the springs of Leuk in Switzerland deposits 2000 tons of calcium sulphate a year. When the solutions are far less concentrated, as in the instances of rivers flowing along the surface, the amount of dissolved minerals carried along amounts to a very great deal. Every day the Thames carries 1500 tons of dissolved mineral matter to the sea; the Mississippi carries more than a 100,000,000 tons a year. Much of this dissolved mineral matter is brought to rivers by streams which rose as springs and were underground

waters before their birth. On the average the minerals dissolved in rivers weigh about a third as much as the undissolved sediments that the rivers carry, and from them the sea receives each year nearly 5,000,000,000 tons of mineral matter in this form. Another way of stating the same conclusions is that, irrespective of the sediments, the dissolving action of the surface waters would, were there no compensating action, lower the land surfaces by a foot in 13,000 years.

Bischop, quoted by Geikie,[1] remarks that carbonic acid, bicarbonate of lime, and the alkaline carbonates bring about most of the decompositions and changes in the mineral kingdom. It is evident that underground waters charged with these constituents do a very great amount of work both of a destructive and a constructive kind. Sandstone may be made more porous. Rocks with their cements removed may crumble and desiccate or disintegrate; they may be split asunder by excess of moisture. Limestone, which lends itself peculiarly well to treatment, may be hollowed into caverns. The caves of Derbyshire, those of the Ardennes, and of Kentucky on a larger scale, are most often quoted as examples of this form of operation. Even in hollowing out these excavations the mineral-charged water, depositing itself as stalactites or stalagmites, gives evidence of the reverse aspect of its capacity.

Local earth sinking may occur as a consequence of these underground excavations, and the larger number of landslides are also to be set down to the action of underground water. Altogether underground water is a most important geological agent, continually adding or subtracting its constituents to or from the rocks which it washes. It is of biological as well as of geological importance, because much of the dissolved material which it brings to the surface is

[1] "Text Book of Geology," Vol. I, p. 488 (4th ed., 1904).

carried to the sea, and having been there deposited, is used by the marine organisms of the sea to make their shells. Without the mineral matter brought to the sea by springs and rivers, many of the shell-bearing organisms would never have arisen.

CHAPTER XII

STRUCTURAL FACTORS

Deposition of stratified rocks—Shallow and deep sea deposits—The floor of the sea—Processes of strata formation—Igneous rocks—Rock reservoirs—Classification and descent of rocks—Derived rocks.

IT will be evident, apart from any considerations stated in the preceding chapter, that all the factors of disintegration or erosion are furnishing material for reconstruction. The silt carried from the land by running water awaits only a pause or alteration in the movement of the water to settle down elsewhere; the material carried in solution from the rocks seeks new combinations; the erosion of wind or sea is but a preliminary to the formation of strata. Strata which are merely the reduced rubble of rocks or of other strata, are laid down in lakes, or wherever the movement of rivers slackens sufficiently to allow the solid particles to sink. Strata are similarly formed wherever running water joins the sea. The coast lines of the continents differ a great deal in different localities. Along the great American ridge which runs almost without interruption from Alaska to Cape Horn the slope of the mountain chains of the Andes or the Cordilleras may be pictured as being continued past the junction of land and water deep into the sea. Off the west coast of Europe the continental slope is less steep and there is a broad fringe of shallower water stretching from the coast to the edge of the continental shelf where deep water begins. But the conditions off the west coast of Europe may be regarded as sufficiently typical to illustrate the method in which strata are laid down.

From the coast line to the edge of the continental shelf

at a depth of about 100 fathoms is a sea-bottom consisting of boulders, gravel and sand, all materials borne from the land by the rivers, or broken away from the coast by the sea waves. Sand and mud are carried in suspension by the water or are rolled along the sea-floor by the action of the tides and currents. They are then laid down evenly, forming flat areas of sea-bottom with slight undulations or shallow channels. Finer mud is carried out farther, before it, too, settles and is deposited. Beyond the edge of the continental shelf the bottom deposits become finer and finer till in deep water the region of blue and green muds[1] is reached. These materials stretch out great distances and are generally characteristic of the sea-bottom within the 1000 fathom line. But within the 1000 fathom line we begin to find deposits of a different kind. As the depth and distance from the land increase, there is less and less material derived from the land, and more matter arising from the ultimate *decomposition* of minerals and rocks, and accompanied by the remains of such marine organisms as belong rightly to the coasts. The deposits brought from the land are rich in silica. One half to two-thirds of their weight is constituted of this mineral. But the marine organic deposits are rich in lime. Calcium carbonate occupies in them the place and proportions of silica in the earthy deposits. The marine organic deposits consist largely of the broken down and comminuted remains of the skeletons of such animals and plants as form calcareous shells or skeletons.[2] These are corallines or calcareous algæ, corals, echinoderms such as starfishes, sea-urchins, polyzoa, the spicules of calcareous sponges, and the shells of mollusca or crustacea.

[1] The colour of these muds depends partly on the changes undergone since they were deposited. Green muds are most often found off bold coasts where sedimentation is slow. Blue muds indicate a lack of oxidation. Both muds resemble shales.

[2] "Conditions of Life in the Sea," by James Johnstone (Camb. Univ. Press) 1908, pp. 33-34.

Shallow and Deep-sea Deposits

The foregoing deposits are sometimes spoken of as "Benthic" deposits to distinguish them from the terrigenous or land-derived deposits with which they are mingled. Beyond them lie at greater depths those deposits on the deep bed of the ocean which are called pelagic.[1] Outside the 1000 fathom line the nature of the sea-floor is strikingly different from that within the continental area. While the remains of animals living on the sea-floor do indeed occur, these are not abundant and do not constitute a notable proportion of these deposits, and the only material composing them which has a terrestrial origin is such as has been derived from the material discharged during volcanic eruptions. Pumice from such a source finds its way into the sea directly or after carriage by rivers (or, again, from marine volcanoes) and sinks to the sea-bottom there to undergo decomposition. These substances occur in the muds or oozes which form the floor of the deep oceans, but mud or sand derived from the detrition of the land is not to be found there. Instead we find a material which is almost entirely derived from the remains of the animals and plants which live in the body of sea-water extending from the surface to the bottom.

At a limited distance from the land and still within the limits bounding the area of terrigenous deposits may be found the *Pteropod ooze*, a substance which is characterized by the preponderance of the shells of pteropods, and pelagic gasteropods which live at the surface of the sea in great shoals. From about 500 to 1000 fathoms is the depth of the sea where the pteropod ooze is found.

Outside these limits the area of the *Globigerina ooze* is found. The globigerina ooze extends over a greater area of deep sea than any other deposit. It is formed of the

[1] The organisms which, like sea weeds and the zoophytes, live attached to the sea-bottom, or like molluses or echinoderms live there more or less permanently, form the "Benthos". The word was coined by Haeckel.

calcareous skeletons of the foraminifera which inhabit the upper layers of the sea. Its average range in depth is somewhere between 1500 and 2500 fathoms.

But beyond a depth of 2500 fathoms, or about three miles, the ocean floor again changes its character. There are few skeletons of the fragile foraminifera here to be found because so slowly do they sink that before their journey is completed they have been almost entirely dissolved. Siliceous deposits take their place; and thus we arrive at the *Radiolarian ooze.* The radiolaria are protozoa which have a siliceous skeleton, and which inhabit nearly all layers of the sea. Their soft parts decompose slowly, and the siliceous remains accumulate into a deep-sea deposit.

The other and principal deep-sea deposit is the *Red Clay*, within the area of which are embraced even greater depths than are covered by the Radiolarian ooze. In some part this deposit is formed of living creatures; but it appears to be chiefly inorganic in character. Its origin may be ascribed to the pumice and volcanic ash which has been ejected from terrestrial or submarine volcanoes. At the great depths where it is found all organic material has disappeared from the deposits. It may have been dissolved by the sea-water. It has been more probably broken down by marine bacteria and these minute organisms may similarly dispose of a good deal of the lime and silica which falls perpetually through the water, but of which there is less on the sea-floor than the abundance of skeletons of marine animals would lead one to expect.

"In addition[1] to these substances comprising the oceanic bottom deposits there are of course many others . . . such as the well-known *Diatom ooze* of the Antarctic. At an average depth of about 2000 fathoms there is a wide band of soft white ooze covering the sea-bottom between the parallel of 40° S. and extending to the Antarctic circle and

[1] "Life in the Sea," by J. Johnstone, p. 37 *et seq.*

completely surrounding the southern hemisphere. This band has an area of over ten millions of square miles. The material composing it has resulted almost entirely from the siliceous shells of diatoms which live in enormous numbers at the surface of the Antarctic seas, and which dying, sink to the bottom, where their skeletons accumulate. Then, too, in all these oceanic oozes other substances are found. Throughout the deep basins of the oceans there are found the teeth of sharks and the ear-bones of whales, etc., the only parts of the skeletons of these animals which withstand the solvent action of the sea-water at the great depths in which they are found. . . . All over the sea-bottom are found the peculiar manganese nodules which were first noted and described during the voyage of the *Challenger*. Finally, it has been recognized that in the deepest parts of the sea there are particles in the oozes which result from the combustion of meteorites that have entered the atmosphere from without. These should of course occur in the deposits of all depths, but in most their presence is masked by the preponderance of other substances, and it is only in the deposits of the very deep basins, which are formed with extreme slowness, that they can easily be recognized." [1]

[1] Murray and Irvine (*Proc. Roy. Soc. Edin.* Vol. LXXXII) give the following table showing the estimated area, the mean depths, and the percentage of lime in relation to deep-sea deposits.

Deposit.		Area in Square Miles.	Mean Depth in fathoms.	Mean percentage of Lime.
Oceanic deposits.	Red clay . . .	50,289,600	2727	6·70
	Radiolarian ooze .	2,790,400	2894	4·01
	Diatom ,, .	10,420,600	1477	22·96
	Globigerina ,, .	47,752,500	1996	64·53
	Pteropod ,, .	257,100	1118	79·26
Terrigenous deposits.	Coral sands and muds	3,219,800	710	86·41
	Other earthy deposits	27,899,300	1016	19·20

The Floor of the Sea

A word may be said here of the general conditions on the floor of the sea, conditions which moved Mr. Rudyard Kipling to his poetic description of "the great grey level plains of ooze, where the shell-buried cables creep" and where in the soundless darkness the cabled words of men "flicker and flutter and beat". His description in many respects is scientifically accurate. At an average depth of a hundred fathoms the darkness is that of a moonless and cloudy night; below that depth the darkness is complete, though deep-sea fishes and other animals may have some degree of perception, its nature unknown to us, of atmospheric radiation. "At the bottom of a deep sea," remarks J. Johnstone, "uniform conditions obtain. The bottom is a flat plain with few inequalities, for those indicated by the sounding machines are slight compared with those we have on the land, and though precipitous declivities must occur these are very exceptional. The sea-bottom is composed of soft semi-fluid oozes into which objects must easily sink. A uniform temperature, which is that of the freezing-point of fresh water or a degree or two above it, obtains. Profound or absolute darkness, broken only by the light of some phosphorescent creation, is there. Daily or seasonal changes never occur, and almost absolute uniformity of conditions reigns. Add to this the enormous pressure of *the overlying* water; which is about fifteen pounds for every five fathoms of depth, and we have conditions in which it is almost incredible that life as we know it can exist." To this description we may add that of Chamberlin and Salisbury:—[1]

"The bed of the ocean, like the face of the land, is affected by elevations and depressions, and its deepest points are about as far below its surface as the highest mountains are above it. There are areas of the sea-bottom which, as

[1] "Geology," Vol. I, pp. 311-12.

a whole, may be compared to the plains of the land, and others which may be likened to plateaus, and the lines of gradation between them are often as indistinct as they often are on the land. There are mountain peaks, chiefly of volcanic origin, and depressions comparable to the great basins on the land. But apart from these general features there is little in common between the topography of the sea-bottom and that of the land. Mountain systems are for the most part absent, though certain islands like Cuba and some of its associates may be regarded as the crests of systems which are chiefly submerged. If the water were drawn off the ocean's bed so that it could be seen as the land is, the most impressive feature would be its monotony. The familiar hills and valleys which in all their multitudinous forms give the land surface its most characteristic features are absent. . . . In the sea the dominant processes tend to monotonous planeness."

Processes of Strata Formation

In the remote monotonous depths of the sea, the structural work of the planet is being performed. The clays, the globigerina ooze, the diatom ooze, the earthy deposits are the first steps in the life of new strata. The deposits of the really deep sea—such as the volcanic red clay—seem the only ones to find no correlatives in the rock formations of the land. Other deposits are being mingled with them. Murray has estimated the volume of the sea at nearly 324,000,000 cubic miles, or fifteen times the volume of the land above its level. In this vast volume of water are accumulations of mineral matter and gases which in the aggregate are of immense extent. Every 1000 parts of sea-water contain more than thirty-four parts by weight of mineral matter. Chloride of sodium is easily first, and in every cubic mile of sea-water there are more than 117,000,000 tons of it. A more striking arithmetical consequence of

estimating the amount of mineral matter held in solution by the sea, is one which shows that if the mineral matter could all be converted into solids, it would cover the ocean bottom to a depth of 175 ft., or all the land of the world with new strata about 450 ft. deep. If on the other hand it were concentrated in the shallow waters about the borders of the lands, it would stretch out to all the ocean regions which were less than three-quarters of a mile deep and would add some 20,000,000 square miles to the land surface of the globe, or about one-third of its present area.

What the raw materials are for strata-making may perhaps be gathered from the foregoing paragraphs. The processes next submit themselves to consideration. The remote, immobile bottom of the sea is immobile only to superficial observation. It is in reality subject to the influences which affect the land though in a differing degree. The movements of the Earth's crust affect it; it is disturbed by vulcanism; it suffers the converse of land erosion. On the land the hills and the more elevated portions of the surface are continually graded to lower levels. In the sea there is a continual and almost universal addition to its contours; and degradation is virtually confined to shallow water, or to what might be called the highlands of the sea. The chemical processes of the sea-water are of two kinds. If the water at any time becomes over-saturated with a mineral, then the mineral is precipitated, and accumulates as a sediment at the sea-bottom. On the other hand, the solvent action of the sea-water (as when the bottom is of a relatively soluble rock, like lime carbonate) may smooth down and degrade the sea-bottom. What is true of the sediments of the sea is true in kind though not in degree of sediments deposited in lakes. Even the limestone of the sea has its correlative in some lakes, brought thither by the shells of fresh-water animals, or from the calcareous secre-

tions of some plants, or thrown down by the water supplying the lake. A few lakes are salt or "bitter". Salt lakes contain sodium chloride, and usually magnesium chloride and sulphates. "Bitter" lakes contain a good deal of sodium carbonate; and the constituents and proportion of salts differs a great deal. For example, the Caspian Sea which, like the Black Sea, was probably once a portion of the ocean, contains on the average more salt than the sea. The Great Salt Lake and the Dead Sea, which had fresh water ancestors, contain none, and Lake Van, in Eastern Turkestan, which is the densest body of water known, contains about 33 per cent of salt. The minerals in lakes are usually precipitated as sediments according to their insolubility. Thus gypsum is less soluble than salt; and so on old lake beds we find layers of gypsum underneath the salt.

The assemblage of these facts is in itself sufficient to indicate the way in which the sedimentary strata of a planet are laid down. But the mode of formation is symbolic in a rather wider sense of the mode of formation of all rocks; because all rocks are descendants of other rocks. At the root of the family tree are the igneous rocks, or the rocks which presumably were originally molten material. For this material the name "molten magma" has been coined; and whether we accept the theory that the planet was once a mass of whirling and molten liquid, or the theory, to which more prominence has been given in this volume, that it represents an assemblage of planetismal fragments, we yet have to admit a period when the greater part of the solid mass was fused together by fiery heat.

Igneous Rocks

At some stages in the planet's history—and perhaps it was only possible at certain stages of the planet's growth—rock-fluid from these molten reservoirs flowed over portions

of the planet's surface.[1] But by far the greater part of the planet's crust consists not of rock material which has flowed out, but of rock material which has been pushed through, or which has "intruded" among other rocks. Even the imposing volcanic outpourings of rocks which cover portions of the earth's surface have been accompanied by even more voluminous "intrusions" underneath the crust, and not yet revealed by the wear and tear of erosion. "In India ancient 'intruded' rocks of unknown depths occupy a larger area than the Deccan lava sheet. The vast tracts of granitoid and gneissoid rocks in Scandinavia, Canada, Brazil and other countries must greatly outweigh the known volcanic rocks of all ages, and each such tract is only part of a larger concealed mass."[2]

An individual volcano may be fed from its own reservoir of "rock magma"; and when in a considerable volcanic region the lavas thrust out are similar in character, it is probable that underneath the volcanic tract is an extensive inter-crustal basin, or chain of basins, which feed the smaller reservoirs. The small local reservoirs of individual volcanoes may not lie very far below the surface; but the case is different with the large or permanent inter-crustal reservoirs which are postulated. Harker remarks of these deep reservoirs that "we must seek the immediate cause of igneous action, not in the generation of heat, but in the *relief of pressure* in certain deep-seated parts of the crust where solid and molten rock are approximately in thermal equilibrium. . . ." (In such a mixture, a relief of pressure, like the removal of pressure from the surface of a boiling liquid or of a liquid on the point of boiling would produce a change of relations analogous to that of altering the temperature.)

[1] As for example in the Deccan of India where the extruded molten rock covers an area of 200,000 sq. m. with an estimated thickness varying from 200 to 6000 ft.

[2] "Natural History of Igneous Rocks" (Harker).

Such a magma basin or parent reservoir is available as a source which furnishes the material for extrusive processes or intrusive processes; it may become at particular stages frozen solid and then be again re-melted; it may be divided as activity wanes into smaller reservoirs. It is not possible to say with certainty at what depths these magma reservoirs exist; but some thirty or forty miles has been hazarded as a probable depth. In these natural crucibles the parent igneous rocks are, or were, prepared.

Rock Reservoirs

In the igneous rocks all the known elements of the planet may be found, though only eight of them, oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, or potassium, are principal constituents. These elements form various chemical combinations, out of the combinations spring various minerals; from the minerals are derived the rocks. The union of oxygen with the other seven elements is the master-key of the combination; and the result of this union is the following series of oxides: silica, alumina, three iron oxides, magnesia, calcium oxide or lime, soda, and potash. We may omit consideration here of various sources of complexity in combination and note only in passing that the number of silica minerals in igneous rocks is large; and that a few minerals make up the great mass of igneous rocks. These few are: quartz, the feldspar minerals, the iron-magnesian minerals, and the iron oxides. The feldspars and the iron-magnesias are the leading silicates of the earth's crust.

A reservoir of molten rock is not like a caldron of molten metal. Gold is always gold; and lead is always lead, whether they are liquid or solid; and if the pressure put upon them remains the same they will always melt, or being molten will become solid, at the same temperature. But a molten rock is not a simple liquid element; it is a

mixture of different chemical liquids, and it behaves differently in different circumstances. If it and its rocky constituents always solidified when the temperature fell below a certain point, then we could easily arrive at the pedigree of the rocks. Thus if a molten granite composed of molten quartz, molten feldspar, and molten mica were allowed to cool, then since quartz wants more heat to melt it than the others, we should expect it (on the analogy of metals) to be the first to solidify. The contrary is the case; the quartz is the last. That is because a molten rock is not an elementary liquid but a chemical solution, or rather a mixture of chemical solutions each of which reacts on the other, and each of which, if we may use a paradox, contains the other.

One or two examples of the curious behaviour of solutions are familiar to people who know little about chemistry. Sugar, for example, melts more quickly in hot water or hot tea than in cold water; but it will enter into solution less quickly if milk be added to the tea. If we sought to recover the sugar from these solutions, then the rate or the temperature at which the sugar could be recovered would not be the same in the two cases because of the chemical reactions of the milk on the sugar. Again if snow, sugar and salt be mixed they will form a solution at a temperature below the freezing-point of snow—and a good deal below the freezing-point of sugar or salt. If the liquid solution be then submitted to a low temperature, the sugar and salt will not solidify (or crystallize) out, at their ordinary freezing or solidifying points; but will wait till the water has become solid and left them behind,—forced them, in short, to take the solid state. If, however, there is a good deal of sugar and salt and little water, the sugar and salt will become solid before the water has frozen into ice. From these common instances, to which the behaviour of molten magmas of igneous rock is similar, we may expect to find that the

solidification of rocks, and the melting of rocks, depends on many varying circumstances—on the kind of constituents, their quantities, and their chemical relations to one another.

A liquid magma, in the first instance, is like a fluid glass, if we make the distinction that glass is a rather simple silicate or mixture of silicates, while the rock magma contains a great many. If this magma—as in the case of an expelled sheet of lava—cools very quickly it cools into a glass; if less quickly, then partly into a glass and partly into crystals; if slowly—slowly enough—then into crystals. There are intermediate cooled rocks in between these stages, and in general the slower the growth the larger the crystals. A modification of the form of the rock will take place when lavas are violently shot into the air from volcanoes; because in such cases the glassy rock is partly shattered into dust by explosion; and it is filled with bubbles of gases, so that part of the volcanic product is dust and part pumice.

Classification and Descent of Rocks

Of the kinds of igneous rocks thus classified the *obsidians* are examples of a compact glassy rock. Varieties of glassy rock in which embryo crystals are more visible are the *pitchstones*, which resemble solid pitch in appearance. In the category of the glasses are also *perlite* and *rhyolite*.

When the cooling has been a little slower and distinct crystals formed and floated in the magma, while the rest of the liquid affected by their presence solidified as a glass or as a mass of small crystals, the result is *porphyry* or *porphyritic rock*. It is the large crystal which gives the distinctive aspect to the rock. If the remainder of the mass consists of small crystals, it is called *granular;* if the crystals have become larger the next class of rocks is approached.[1]

[1] Instead of glassy porphyritic and granular the terms vitreous, hemi-crystalline and holocrystalline are used. Geikie "Text-Book of Geology," 4th ed., Vol I, 1903, p. 196. Geikie adds: "MM. Fongué and Michel

In the next class the magma has become all crystals. The *granites* come under this heading, though it has lately been proposed to put them into a section of the class just preceding this one. But in general the granites may be defined as aggregations of crystals of quartz, felspar and mica. The magmas whence they came were rich in silica, alumina, potash and soda; and the quartz includes the largest share of the silica. Rocks akin to granite are the *Syenites*, which have a little more iron and less silica than granite, the *Diorites* which have less silica and more earthy material; the *Peridotites* poorer still in silica.

The *Basalts* include rocks which appear to be nearly homogeneous owing to the minuteness of the crystals; and these rocks glide into the *Dolerites* which are basalts of coarser crystallization. The *Gabbros* are coarsely crystalline rocks a step nearer to those just enumerated. It may be said of nearly all these classes that they glide insensibly one into the other.[1]

Levy, pointing out that most eruptive rocks are the result of successive stages of crystallization, each recognizable by its own characters, show that two phases of consolidation are specially to be observed; the first (porphyritic) marked by the formation of large crystals (phenocrysts) which were often broken and corroded by mechanical and chemical action within the still unsolidified magma; the second by the formation of smaller crystals, crystallites which are moulded round the older series. In some rocks the first of these phases, in others the second, is alone present." Other systems of classification have been proposed, including that of Prof. Rosenbusch, who has proposed to group the igneous rocks in three great sections, first the deep seated rocks which have consolidated as plutonic or intrusive masses far below the surface; second dyke rocks which may have been injected as dykes or veins at a less distance from the surface, though some portions of them may have come above the ground in volcanic eruptions; third effusive or volcanic rocks which have escaped to the surface and have there solidified—they possess a porphyritic structure. Each of these three great divisions is further separated into families according to mineralogical composition, beginning with acid types and ending with the most basic. Some American geologists give the designation "holocrystalline" to the class, which in the text we have called "granular"; and speak of the rocks in which the magma has become wholly crystalline as "phanerites".

[1] *Syenite.*—Rock consisting of a holocrystalline mixture of alkaline felspar (orthoclase) and compact silicious rock (horneblende) to which quartz, biotite

The foregoing classification is by no means complete. It aims merely at denoting the general characters of the primary rocks. From them other rocks are derived; and the derivatives are spoken of as secondary rocks, though it is quite evident that the primitive rocks may themselves be derived. It can also be shown that while there are processes which by fission or chemical decomposition produce from one rock other rocks which are its descendants, so, conversely, there are recombinations, physical and chemical, which build up rocks.

Derived Rocks

Simplest among the derived rocks or secondary rocks are those which are the products of disintegration merely—sand consists essentially of grains of quartz. When the surface rock is chemically split up and the silicious and clayey parts are left, the lime, soda, etc., are borne away to the sea. Shales, sandstones and conglomerates are in the four series of these derived rocks. Limestone, which has passed through the stage of being an animal skeleton or shell, but which was first carried from the rocks by water, is another form of derived rock; so are the *dolomitic* rocks in which mag-

magnetite, etc., may be added. Its proportion of silica is between 50 and 60 per cent.

Diorite.—Comprehends a group of rocks which, possessing a granitic structure differ from the granites in their much smaller percentage of silica, and from the syenites in containing plagioclase (chiefly a soda-lime felspar) instead of orthoclase.

Peridotite.—These rocks stand at the extreme end of the basic igneous rocks as the granites stand at the opposite end of the acid series. They contain no felspar, and consist of olivine with horneblende, mica, magnetic iron, This proportion of silica is nearer 40 than 50 per cent.

Basalts.—A group of black extremely compact, apparently homogeneous rocks, in which the component minerals are to be observed only under the microscope. The minerals are plagioclase, olivine, magnetite, etc.

Dolerite.—The Dolerites are usually holocrystalline rocks including many which once were termed green stones.

Gabbro.—Consist of plagioclase (labradorite) with olivine and magnetic iron.

nesia mingled with the deposited lime. *Gypsum*, *hematite* (and other iron compounds) and *silicious* deposits, flints and cherts, are all examples of derived rocks.

Underground waters always carrying some mineral in solution, and acting often in circumstances of great heat and pressure, alter the chemical constitution of the rocks of the crust; and the rocks possess in themselves by virtue of their chemical constitution the potentialities of alteration, decay and reconstruction. Just as iron rusts, or the surfaces of stone in smoky cities decay or acquire a new surface—so oxidation and carbonation, or processes which are the reverse of these, are going on in the Earth's crust. Just as also the oxides of mercury have different forms, according to the heat applied, or just as tin assumes different forms, so the molecules of some of the rock constituents rearrange themselves, or the elements enter into new chemical relations. Of late years the phenomena of radio-activity have become familiar to everybody, and, even without the contributory causes of heat and pressure, rocks and even elements may change their constitution as well as their constituents.

If disintegrating action is not opposed by a reconstitutional process equal as well as opposite, the rocks that are broken up are always forming new combinations. The muds and sands are hardened by pressure and bound together by natural cements; and thus arise sandstones, shales, limestones, breccia, volcanic tufas, and agglomerates. Films of cementing silica may be deposited about the grains of rocky debris, and quartzite or oolite[1] may thus be formed—

[1] "*Oolite*—a limestone formed wholly or in part of spherical grains having the aspect of a fish-roe. Each grain consists of successive concentric shells of carbonate of lime. . . . The calcareous material was deposited round some minute particle of sand or other foreign body which was kept in motion so that all sides could in time become encrusted. It is now known that minute algæ play an important part in some of these depositions" (Geikie "Text Book," *op. cit.*, Vol. I. p. 191).

or the silicious cementing may fill hollows and form agates—and crystals. Rocks formed and minerals deposited in the foregoing ways have been reconstructed under normal conditions of heat and pressure. But abnormal conditions of great pressure or great heat, or the two combined, may profoundly alter the character and appearance of rock. Slaty structure is a result of pressure; rock "schists," among which are commonly embraced twisted or contorted crystalline rocks, arise out of very great pressures. Heat such as might be applied by an intrusion of lava or molten rock will bake the rocks on which it operates. Limestone will be altered thus into marble; a quartz sandstone becomes quartzite; and mica schists and gneisses occupy the place of slaty rocks. When heat and pressure combine, some of the crystalline rocks are broken down, while clastic rocks are rendered more crystalline; but the tendency in effect in both cases is to render the rock product more schistose and contorted in internal structure.

CHAPTER XIII

EARTH MOVEMENTS

Movements of the crust—Spasmodic earthquake movements—Slow continued movements—Crumpling—Tangential pressures—Earthquake areas—Explosive uplifts—Volcanic outbursts and lavas—Disconnexion of vulcanism and earthquakes—Foundations of mountains—Mountain building and radio-activity.

WHEN the circumstances of the laying down of strata are recalled two characteristics of the deposited strata will be evident. The first is that the sediments will have been laid down in nearly horizontal planes; the second is that any deposited stratum of sediment must gradually thin out as it recedes from the source of its materials. The sediments have been derived from the breaking up of the land surface; they are therefore necessarily thickest in mass, as well as coarsest in texture nearest to the supply and become more attenuated and finer-grained as they are deposited farther away. The deposits at the present time on lake-bottoms, river estuaries, and sea-bottoms are an evidence of this unaltering law of sedimentation. But as it is barely necessary to say, actual observation records innumerable instances of strata which are far from being horizontal. Some agency has been at work altering their dip, crumpling them, contorting them, breaking their continuity, shearing them, uplifting one portion of them above another, or even reversing the two portions of a sedimentary bed of rock, as one might close an open book. These evidences of movement of the crust, common as they are

among sedimentary rocks, are more common in igneous rocks, and most common in the most ancient rocks known. In the Archean rocks a distorted condition appears to be nearly universal. In the preceding chapter the comparatively minute causes, which by their aggregation both in time and in extent, profoundly modify the character and appearance of rocks, have been examined. But for the distortions, foldings and alterations in the strata, some other cause is usually sought, and is assigned by the majority of geologists to movements of the Earth's crust. It is suggested that the causes which crumpled the strata are the same as those which uplifted the mountains; and that both are due to movements of the Earth's crust. There are two kinds of movements in the Earth's crust—those which are perceptible, spasmodically or intermittently; and those which are to be inferred. It is possible that they are allied; and that they spring from the same cause.

Earthquake Movements

The intermittent or spasmodic movements are the earthquakes, great and small. The inferred movements are those which we should expect to be the result of the cumulative transfer of muds and sands from the region of the land to the region of the sea. It is possible that the transferences of weight may intermittently upset the balance of the Earth's scale pans and cause Earth movements. It seems more probable that some other cause is operating independently to uplift the land platform or depress the sea basin. "It has been frequently observed that regions of great denudation,[1] which are invariably lofty and mountainous, maintain their altitudes by positive uplifting about as fast as they are torn down and removed by denudation. We have also the fact that regions where great sediments have been laid down, have continued as shallow water areas while the process has gone

[1] "Earthquakes," by C. E. Dutton, p. 31 (Murray).

on, and have sunk as fast as the sediments were piled upon them. The Palæozoic system of the Appalachian region (North America), 30,000 feet thick, was all deposited in *shallow waters:* for every stratum carries shallow water fossils. The Mesozoic system of Colorado and the Plateaus, 11,000 feet thick, was also deposited in shallow water. . . . The coast range in California and Oregon was also a shallow water accumulation. On the other hand, the mountain ranges which supplied these western sediments are still standing, and it is not probable that they were ever any higher than they are now. Yet their present mass is but a small fraction of the mass of their own ruins which surrounds them." Major Dutton here postulates some cause which continues to uplift mountain ranges. The same idea was considered in a different way by Sir Archibald Geikie in his address to the British Association at Dover (1899), in speaking of the disturbances which traverse mountain chains "and find their violent expression in shocks of earthquake. Are the disturbances due to a continuation of the same operation which at first gave birth to the mountains? Should they be regarded as symptoms of growth or collapse? Are they accompanied with even the slightest amount of elevation or depression?" We cannot tell.

The science of earthquakes, in spite of the genius and activity of those who pursue it, lags behind because its observation must remain unsupported by experiment; and as yet no one has followed up Geikie's suggestion of making minutely accurate measurements of the heights of points in the Alps, so as possibly to discover whether the Alps as a mountain chain are still growing or are now subsiding.

Slow Continued Movements

We shall assume that the causes at the root of these upheavals and subsidences were the slow oscillatory movements of the planet in its efforts to arrive at a condition of

gravitational stability. These movements, as described in the account given by Prof. Love's hypothesis, might result in a pendulum-like oscillation of the waters of the Earth to and from the poles. From this movement of the Earth's waters one may derive a simile. An ocean swell in its forward movement means at every point a rise and fall. Over each ripple of surface[1] there is a curving and an uncurving. So it has been with the see-saw motion of the earth's rocky crust. Slow but irresistible, with prolonged pauses, these movements of the crust as demonstrated by the strata were of necessity accompanied by bending of rock surfaces originally flat. We can in the geological record find examples of all kind of flexure, from a single slight convexity or concavity to great folds such as constitute the Jura mountains, the Carpathians or the Appalachians.

If Geikie's suggestion as to the measurement of relative heights in mountainous regions has not yet borne fruit, actual observations have certainly shown that some shores are slowly rising and some slowly sinking. Possibly all may be sinking, some faster than others, and the ocean may be sinking also at a rate in between the fastest and the slowest. Geologists are, one may say, united in supposing that a general shrinkage of the planet is going on, carrying down land surface and sea-bottom.[2] Suess has urged that the general shrinkage is so great that the local *upward* foldings and warpings never equal it, and that the real movements are all *downward* though in different degree;[3] but in his last published volume he has resigned this ingenious theory.

[1] "The Physics of Earthquake Phenomena," by C. G. Knott, p. 4 (Clarendon Press, 1908).

[2] "The Face of the Earth," Vols. I-IV. Translated by H. B. Sollas, (Clarendon Press).

[3] Suess maintains that the face of the Earth owes its expression to dimples and wrinkles due to the Earth's having shrivelled with age: but in his last volume, "Das Antlitz der Erde," (Vol. III, pt. ii.) (Vienna, Tempsky;

Between the highest point of the land and the lowest depth of the sea there is a difference in level of twelve miles. There may have been higher mountains in past times, but it seems more likely, taking the chemical effects of erosion into account, that the tendency has been for the continents to become more elevated and the oceans to become deeper, so that we assume that great ocean depths at any rate have never been greater than they are now. Consequently it may be assumed that a difference of twelve miles is the greatest difference. If we take largish areas, such as the plateau of Tibet, which is three miles above sea level, and the extensive Tuscarora Deep whose bottom is five miles below it, the difference in range is eight miles. If we place the average height of the continents against the average depth of the oceans the difference is three miles. That—on the assumption that when the planet first began to take shape, the great continental segments and the great oceanic segments occupied relative positions not strikingly different from those they occupy now—may be taken as rather greater than the differential movement upwards or downwards of the master segments of the Earth's surface. Chamberlin and Salisbury calculate that if all the continents were rubbed down and all the oceans silted up till the Earth's sphere was everywhere smooth and equal, the common surface would lie about 9000 feet below the waters.

Taking this hypothetical new surface as a reference for comparison, it will be seen that the continents have been squeezed up two miles above the common plane, and the ocean basins have sunk about one mile below it. This is merely a rough hypothetical statement which there is no means of verifying. But the total shrinkage of the Earth since it first became consolidated into a planet, is probably

Leipzig, Freytag), he abandons the view that all vertical movements are necessarily downward (J. W. Gregory (Review in *Nature*), 16 June, 1910, p. 451).

much more than these differences in level between continent and ocean basins.

Crumpling

If the one mile which the oceans have sunk below the common plane represented all the shrinkage of the Earth, then the circumference would only have shortened by a little more than six miles. The result of packing 24,000 miles of circumference into the space occupied by 23,994 miles would have to be made to account for all the crumplings which pushed the mountains of the Alps, the Himalayas, or the Cordilleras into folds. But it has been estimated that the crumpled folds of the Alps represent a shortening of seventy-four miles.[1] Even the coast range of California represents a shortening of ten miles. Of course, in estimating the amount of shortening necessary to crumple up the strata so as to form all the world's mountain ranges, one does not add the figures of crumpling for all the mountain ranges together; but having taken a line through a given mountainous tract of folding or crumpling we follow it on a great circle round the globe, and add together all the great foldings it encounters. Usually the line never crosses more than one or two deeply crumpled tracts of the same age; as a matter of calculation the total shrinkage along any great circle is about double the shrinkage which would have given rise to the greatest mountain range it crosses. From these considerations various estimates have been formed of the amount of shrinkage in the Earth's circumference which would have crumpled up the strata into mountains (as one crumples up wax by squeezing it together); and the shortening may have been as much as 200 miles if all the eras since

[1] Prof. Luigi de Marchi of Bologna remarks that whereas Heim estimated the crumpling of the Alps from Zurich to Como as representing a shortening of 120 kilometres he would now have to admit a shortening from five to ten times that amount; and, in consequence, a shortening of the Earth's radius equal to about 100 miles ("Rivista de Scienza," Vol. VI, No. xii, p. 279).

the first known rocks were consolidated. That implies a lessening of the planet's radius equal to about thirty-two miles.

It will be readily perceived that if the fact of this shrinkage be granted, it will suffice to explain the crumpling of strata and the formation of mountain ranges—by tangential or sideways pressure. Some may at first find it difficult to imagine how a solid stratum of sandstone, for example, can yield by bending and not be ruptured in the process. But it has been shown experimentally that a solid will flow like a very sluggish treacly liquid when a suitable combination of forces acts upon it. Even marble will flow. Prof. F. D. Adams and Dr. T. J. Nicolson [1] placed some columns of pure Carrara marble in close fitting iron tubes and then subjected them to level pressure. When the pressure reached about 18,000 lb. to the square inch the tubes began to bulge. The marble was then examined and was found to be permanently crumpled. The marble was still firm and compact, but it could be distinguished at once from the original unstrained rock by its turbid appearance. Microscopic examination shows that the material had broken down along certain lines of shearing. It was permanently strained and was weaker than at first and more susceptible to squeezing. Thus we see that under suitable stresses even cold rock can be permanently strained, and become moulded to new forms by interior alteration, but yet without disintegration. The rock becomes less resistant during the process, and subsequent straining is more easily effected. Bearing these facts in mind we may imagine the bending and folding of strata to take place in the following manner. The strata will begin to yield where the appropriate combinations of pressure and tension are most developed. As soon as a particular part has yielded there will be relief of stress and the yielding will cease. The condition of stress

[1] "Roy. Soc. Proc.," Vol. LXVII, 1900.

favourable to farther yielding will probably be developed somewhere else along the stratum, which may in this way become gradually bent or folded along its entire length.

Tangential Pressures

Let us now consider the causes which develop these tangential pressures. The most evident of them is the force of gravity, which tends to concentrate the particles of the Earth. The particles are usually considered as tending towards the Earth's centre, and as attracting one another. In addition to this attraction are the less understood attractions of cohesion, of chemical affinity, and of the attractions which bind together the constituents of atoms.

The most familiar of the agencies which resist the condensation of the planet towards its centre is heat. As the earth loses heat it shrinks. But in the act of shrinking, its molecules fall inwards, and their movement, their clashings together develop new heat. (In the same way it is imagined that the heat of the sun is maintained. It is shrinking, but the shrinking in itself supplies it with internal heat.) The passage of heat outwards from the planet leads therefore to the generation of new heat.

The resistance to condensation which heat offers is explained by saying that it is due to the impact of the flying particles of heated matter. That is another way of saying that the resistance to compression is in part due to the movements of molecules. Possibly all resistance to compression is due to movements of molecules, or of atoms, or of electrons. Heat is merely one expression of these movements.

In the earlier theories which were formed of the solidification of a planet, it was supposed, first, that a crust formed over the liquid mass and that solidification proceeded downwards—as ice solidifies in a pond. Thus there would not be much temperature change for a long time in the depths.

Some 100,000,000 years would have elapsed before the cooling reached a depth of 160 miles. After the outer shell had cooled so as to be in harmony with the earth's environment, it contracted no more. There could have been no contraction below 160 miles, because that had not cooled at all. Therefore the contraction must have taken place somewhere between them. It was this contraction which was held to have produced the surface wrinkling; because the outer shell was trying to fit itself on the sinking sub-crust. Somewhere between the two levels there must have been a level where there was neither stretching nor shrinking—a level of no stress, which sank as time went on and the planet cooled. This hypothesis, of which mention has already been made in a previous chapter, we may associate with Lord Kelvin.

Then when it was shown that if the pressure on molten rocks was increased the amount of heat demanded to melt them also increased, the second theory arose—which was that the Earth first solidified at its centre and then congealed outwards. The logical prosecution of the idea led to the conclusion that cooling and shrinkage affected the deep interior of the Earth. Therefore the contraction instead of being limited to the outer 200 miles or so, was deeply distributed; and the high central heat was always passing outwards to the surface.

If however the idea that the planet grew by the aggregation of fragments be accepted, then it is assumed that the internal heat also grew with the increasing size of the planet. The internal compression increased; the central heat increased with it, and spread from the centre outwards. The heat therefore went on rising as long as the compression was sufficient to generate heat faster than the planet lost it. Examination of this theory shows, that in the early stages of the planet's history as a solid body, the temperature of an outer shell 800 miles in depth would continue to rise,

while the inner core (about equal to it in bulk) would be parting with heat so fast as to be falling in temperature. A singular result would ensue. The outer 800 mile shell would have to try to fit itself to a shrinking core, while it was itself expanding because of the inflow of heat. This hypothesis leads us to the supposition that there is a flow of liquid rock from the deep interior outwards and that it is even possible that *the shrinkage may originate chiefly in the deeper zones.*

Such are the hypotheses. As however the deepest excavations on the world's surface are less than a mile and a half, and the records of underground temperatures at these insignificant depths show variations not to be reconciled with any formula, they remain hypotheses which are by no means eternal. They are at one in one respect. They appear to show that shrinkage is not enough to account for all the deformations or crumplings of the surface.[2] It is possible that some of the deformations may arise from heating effects which imply a transfer of heat without the shrinking of an interior shell. Or, again, there may have been readjustments of the matter of the outer crust. So far as the Earth's crust can be examined it is intensely heterogeneous in its structure. It perhaps continues to be heterogeneous down to depths of ten to fifty miles. But matter under great pressure tends to assemble in the forms which give greatest resistance to pressure, that is to say into denser forms. If the Himalayas were made of material as dense as that which is under the foundations of the oceans, then from underneath them there would be a real flow of solid matter. We seem compelled to assume that the average density of mountain-building rock is less than the density of

[1] "Geology and Earth History," Chamberlin and Salisbury, Vol. I, p. 541.

[2] According to Rudski a drop of 8° C. in the temperature of the planet in a million years would only bring about a shrinkage of a couple of yards,

the material which lies beneath the ocean waters. The attempt of the Earth to readjust its material would account for many deformations of strata.

We have already referred to the investigations of Prof. Hecker at Potsdam, by which it has been shown that the Earth's solid body yields to the attraction of the Moon. His researches show that the Earth behaves like a steel ball the size of our globe. It yields immediately to the forces which the Moon exerts upon it. It does not wait till after the lapse of hours. Further inferences from his observations are that the Earth is not uniformly arched outwardly and that it varies in constitution and solidity in different parts. "Other investigations have led to the supposition that the Earth is of varying density to a distance of perhaps seventy-five miles, and that below this depth, at equal distances from the centre, the Earth is a homogeneous mass. It is therefore by no means inconceivable that lack of uniformity in the composition of the Earth's crust, of which we find evidence in our continents and oceans, may produce an uneven upheaval of the Earth."[1]

If these causes and their corresponding effects were greater at an earlier stage in the Earth's history, distortion of the rocks would theoretically be considerable. It is not clear, however, that the crumplings perceptible in the mountain folds are distinctive evidence of this action. It is possible that the effect of tidal action of this kind is masked under greater effects. Such action might have affected the distribution of matter within the Earth and have played its part in determining, and in continuing now to determine, the distribution of land and sea. Both on these negative grounds and on the positive grounds of the sculpture of the Earth's surface, and the theoretic strength of rocks and strata, it is simpler to accept the theory that while the outer

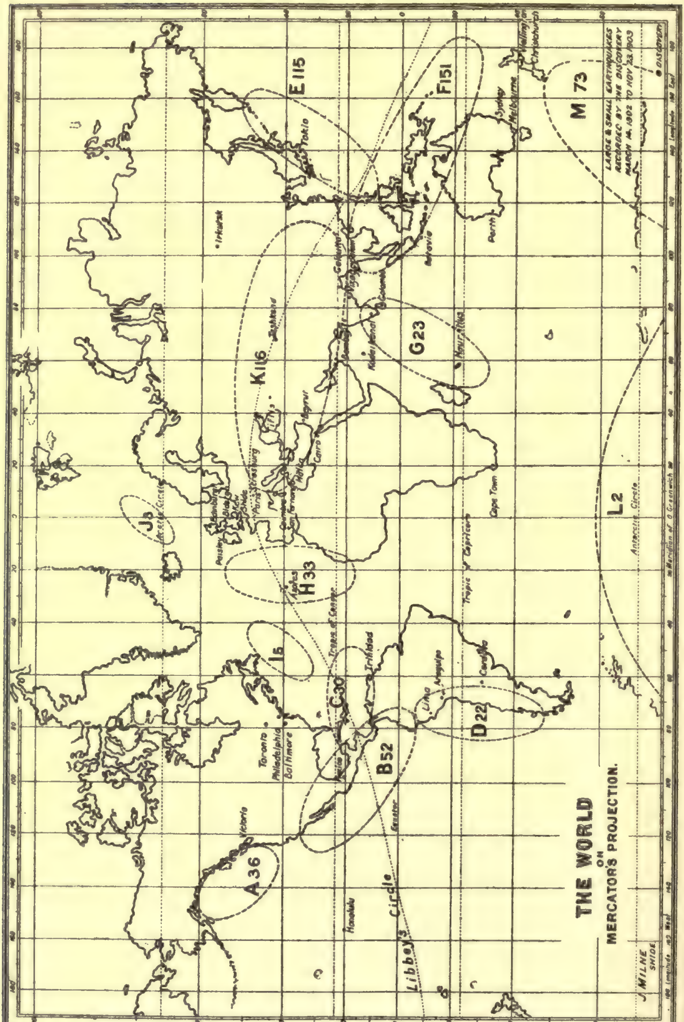
[1] "Harper's Magazine," Vol. CXX, p. 715.

shell of the Earth is always subject to minor warpings, and continual movements, the greater movements are of deeper origin.

Earthquake Areas

It is the consciousness of these considerations which has made geologists and seismologists unwilling to accept the theory lately revived by Dr. T. J. See and expressed by him with great force and lucidity, that all earthquake movements arise from the explosive force of steam and that all mountain ranges have been built by lava injected from ocean beds underneath the edges of continental platforms. Mr. John Milne's earthquake maps of the world,[1] which assigned the origin of great earthquakes to fixed areas, also served to call attention to the fact that these areas were nearly always in the neighbourhood of great inequalities in the Earth's naked surface. That is to say, in the surface as it would appear if bared of oceans. Thus there are areas of earthquake origins along the north-western coast of North America from Alaska to California; another area off the west coast of the Continent from California to Lima; and a third from Lima to Patagonia. A fourth area in this hemisphere is called the Antillean area, and embracing the West Indies intersects the other Central American earthquake area which is situated principally in the Pacific. Other districts of great activity are the area off the coast of Japan which intersects another area covering the East Indies and Australasia. During the past few years the greatest activity has been at the overlap of these last-mentioned districts; and in the ten years 1899-1908, inclusive, the number of large earthquakes springing from these two regions (earthquakes that is to say which were registered at seis-

[1] "Proceedings of the British Association." Reports of the Committee for Seismological Investigations, 1899-1909.



The oval areas are the areas of origin of great earthquakes. The figures within them show the number of earthquakes arising thence in ten years.

mological observatories in other continents) numbered 266.[1]

Dr. Milne at an early stage in his investigations as a seismologist called attention to the fact that all these areas of earthquake origin were situated where the land sloped steeply to the sea. If lines be drawn from the peaks of the Andes, or from the highlands of Japan towards the bordering Pacific Ocean, then for a distance of 120 miles the slope is as great as 1 in 20 or 1 in 30. The inference which Milne drew was that here there was a tendency of the rocks to slip or bend; and that where this tendency existed earthquakes would and did occur. The other inference that Milne derived from his investigations was that earthquakes were frequent in those districts where there are evidences that the Earth's crust is being slowly uplifted or slowly depressed.

Explosive Uplifts

But in Dr. T. J. See's hands these inferences are turned the other way round. The earthquake is not, says Dr. See, the proof that the strata have been strained to such a point that at last they have given way with a snap. On the contrary the earthquake first produced by explosive causes (the mingling of water with fire or the explosive generation of steam) is the force which is at work deepening the ocean, uplifting the land, crumpling the strata and (by the cumulative effect of a number of such explosive uplifts) forming the mountain ranges. According to this view Dr. See regards the concavities in the ocean basins which stretch like broad ditches about a large part of all the continents, and which are from 10 to 300 miles in width, as having been scooped out by steam explosions. The general principle which he conceives as the basis of these excavations has

[1] The total number of great earthquakes thus registered in this ten-year period was 661. (Dr. J. Milne's Annual Report to the British Association, 1909.)

been explained in a previous chapter. Dr. See makes use of it to account for the relative lightness of some mountainous areas of the Earth's crust.[1] "When the tension of the imprisoned steam under the oceans becomes very great, it finally causes the crust to yield along the margins, and mountains are pushed up where the crust breaks parallel to the coast. When an avenue of escape is thus once opened for the lava, it continues active, and the mountains grow higher and higher, unless meanwhile the sea recedes to too great a distance. . . . The formation of pumice everywhere beneath the land, as it is elevated by the steam forming under the oceans, is raising the level of the continents in spite of erosion. So far from contracting the earth may in reality be very slightly expanding. This expansion is due to the formation of pumice nearly everywhere beneath the crust."

Again, "At one time or another the principal oceans form mountains all around them, but in any one geological age the relief may be chiefly on one side except when the ocean is of very great extent, like the Pacific, which therefore is active all round, and obtains some internal relief by the formation of numerous islands". Dr. See would refer the origin of the Himalayas to the expulsion of lava from beneath the Indian Ocean, just as he refers the formation of the great wall of the Andes to the expulsion of lava from the Pacific trough parallel to it. The continuance of earthquakes to the south of the Himalayas he refers to the activity of the ancient sea trough where the Ganges and Brahmaputra now flow; and he is inclined to believe that the strain beneath the Indian Ocean is still relieved by the same movements "which originally formed and are still raising the Himalayan mountains. . . ." "Just as the whole island of Japan is being raised by movements from the Tuscarora Deep, so the whole of the Plateau of Tibet was once raised by an Indian Deep of which these valleys are

[1] "Proc. Amer. Phil. Soc." Vol.XLVI, 1907.

the remains. . . . In the same way the valley of the Po is the remains of the sea valley which was most influential in uplifting the Swiss Alps. But in the case of the Alps, Geikie has shown that there was also a sea on the north which has now quite disappeared, though traces of its former existence still remain." Perhaps the strongest link in Dr. See's chain of reasoning is that which points to the raising of something approaching a submarine range of pumice mountains in the neighbourhood of the Aleutian Isles, north of which several volcanic islands have been uplifted during the last hundred years.

Dr. See has arranged his facts with great ingenuity, and the presentation of his case is the most powerful argument which has ever been advanced in favour of the view held since the days of Strabo, Aristotle or Pliny, that the expansive force of steam is the prime cause of volcanic eruptions and seismic disturbances. We have already shown some of the reasons for believing it to be not entirely explanatory; but it is useful as the explanation of some forms of vulcanism. The percolation of sea-water into the rocky sides of the ocean is a very probable phenomenon, and has often been invoked to explain the volumes of steam which accompany volcanic explosions. But in the most modern view the causes of earthquakes and volcanoes are distinct and their effects are seldom coincident. "The forces which are at work at the time of volcanic eruptions are of a kind different from those exercised during earthquakes or earth tremors. The movements of the earth (Erdbeben) are the manifestation of purely mechanical forces due to the relief of elastic tension; while the volcanic eruption is produced by the expansive force of gases, chief among them being steam, which are held in solution, or dissolved, in the molten rock magma."[1] Geologically as well as at the time, volcanic

[1] F. E. Suess, "Rivista di Scienza," Vol. VI, "Moderne Theorien der Erdbeben und Vulkane".

eruptions produce more marked effects than even great earthquakes.

Volcanic Outbursts and Lavas

A few observations on the nature of volcanic outbursts may serve to show what would be the difficulties of classifying them, together with earthquakes, as the outcome of some common and unaltering cause. The outbursts of different eruptive centres are timed in altogether different ways. In one place volcanic action is nearly continuous; in another the outbursts are separated by periods of quiescence which may be centuries long. It seems as if in some cases, during the resting period, the pressure of gas gradually increased till it became strong enough to burst asunder the solidified material products of previous eruptions, which blocked the principal avenue of the lava's escape. It is possible also that the accumulation of hot vapour reduces the solidified lava to melting point again. The lava thus re-melted is pushed up over the volcanic orifice or through its vents, till equilibrium is restored. Then the eruption stops and the lava is again solidified.

There are marked differences in the character of eruptions. While some are marked by explosive outbursts which expel fine dust, cinders, others merely permit themselves to well over with lava. The first form of eruption usually produces viscous lavas saturated with gas and rich in silicates; the second produces basaltic lavas with little silicic acid. More often the eruptions are of a mixed character; they are preceded by explosions of gas or water vapour which often throw up greater or smaller fragments of the cone as well as cinders collected by feebler outbursts in the past; and these manifestations are followed by great quantities of lava and ash. But whether one considers ancient explosive craters like those of the Crater lakes in the Eifel, or lava cones like Vesuvius superposed on the former cone of Somma; or in other volcanic categories

cones like Etna or the giant welling craters of Hawaii, in every case the force which actuates them is expanding gas. The function of the gas is most apparent when volcanic eruptions are rhythmical in character (as the action of geysers is); and Stromboli supplies an example of this mode of action; but a recurring type of rhythmic action is sometimes to be observed in other volcanoes.

Besides steam, large volumes of other gases characterize volcanic outbursts, notably chlorine and sulphuric anhydride. Often the acids in the ash are disastrous to the region where they fall; after the eruption of Vesuvius in 1906, the plantations of the Bay of Naples suffered severely from the presence of such acids in the waters. Sodic and potassic chlorate were found in the lavas of that eruption. Free hydrogen has been found in the volcanic gases of Iceland and elsewhere; and large quantities of hydrogen were found in the emanations of Mount Pelee. After the principal eruption quantities of gas continue to escape from vents in the crater, or from the cooling lava—steam, alkaline chlorides, sulphuric anhydrides, sulphuretted hydrogen—and later carbonic anhydrides. A coincidence which is entirely relevant is that these gaseous products are found in Icelandic geysers, and in thermal springs (such as Carlsbad). Suess remarks that these gases are not the result of filtration from superposed strata, or the products of collection of underground waters, but are as truly volcanic products as the gases of lava; "they see the day for the first time" ("sie treten hier das erstemal an das Tageslicht"). Volcanic explosions, thermal springs, emanations of cool carbonic anhydride are all manifestations of the same phenomenon—the expulsion of gas from the terrestrial globe—its degazifaction ("die Entgasung des Erdballes"). It is a process altogether different in its essence, from the processes by which the mountains are formed, and of which earth tremblings are the manifestation.

The advocates of a significant connexion between vulcanism and earthquakes have pointed to the "girdle of fire of the Pacific" in support of their theory: and it is true that Prof. Milne's map of Earthquake Origins would reveal at first sight some resemblances to one in which an attempt was made to distribute the world's volcanoes into regions. But while volcanoes do exist in regions shaken by earthquakes—as along the western coast of South America—active volcanoes are entirely absent from Asia Minor, Mesopotamia and the Himalayas, while regions such as Hawaii or Iceland, where volcanic activity is very marked, are outside any of the regions of great earthquake origins. And though local shakings of the Earth do accompany great volcanic eruptions, the area disturbed or shaken is not comparable in extent to that which feels a great tectonic earthquake. Japan has volcanoes and is shaken by earthquakes; but the earthquakes arise either on the east coast, or in the ocean to the east of the islands; and their effect grows steadily less inland, till at the foot of the inland mountains, where there are a number of volcanoes, earthquakes are barely perceptible. Similarly in Mexico the regions most violently shaken by earthquakes are farthest removed from volcanoes. The earthquake regions are near the Anahuac plateau and the Pacific coast; the volcanic regions to the north-west are little disturbed by earthquakes. Again the Atlantic seaboard of the Isthmus of Tehuantepec (Central America) is entirely untouched by earthquakes in spite of the frequent eruptions of the volcano of Tuxtla; and the same independence of action between volcano and earthquake seems to hold good in the greater number of regions bordering the Pacific coast.

Disconnexion of Vulcanism and Earthquakes

The absence of relation between earthquakes and volcanoes is not postulated merely on this superficial absence

of an undeniable connexion between them. The eruptions of a volcano are merely the last, and relatively insignificant manifestation of something that has been going on below the surface. When a volcano has become extinct, and has ceased to accumulate cinder and ash, erosion may at length sweep its cinder cone away and lay bare its foundations. It can then be noticed that the lava accumulated in its depths,—in crevasses, dikes, and funnel, has not solidified in the same way as surface lava. Instead of being a mass of porous pumice, crumbled and baked, or of volcanic glasses with masses of free crystals—it is found to be composed of crystalline rocks which owe their crystalline structure to solidification which has been effected slowly and under pressure.

If denudation goes on it may disclose presently a pillar or pillars of crystalline rock. Then presently rocks traversed by veins of eruptive rock. Finally, in place of the original mountains or volcanic cones one finds intercalated between the stratifications of the foundation extensive blocks of material which at first sight have nothing in common with the volcanoes of the surface, either in respect of their dimensions, their form, or their rocky structure. These rocks are called batholiths; and from the fact that the deeper we go the greater they are, we conclude that these masses do not rest on any foundation of sedimentary rocks but are continued downwards to unknown depths. Granites, diorites, syenites are the rocks of which batholiths are chiefly constituted. Their appearance among the most primitive of sedimentary rocks gave rise to the theory among the geologists of last century that these were the earliest rock foundations of the planet's crust; and they were called Plutonic rocks to distinguish them from more recently erupted rocks. Leopold van Buch and his school drew from them the conclusion that mountain chains were originally caused by the upward surging of these rocks from the depths. The closer examination of what may

be called the architecture of mountains has, however, convinced the majority of geologists that mountains have been uplifted not by a central ascensive force, but by a one-sided pressure which has pushed them in folds one against the other. This is shown in the clearest way by the existence of chains of mountains composed of a series of little folds back to back, without any central axis and showing no trace whatever of any eruptive rock. Such for example are the Swiss Jura mountains. It is true none the less that the great chains of mountains often disclose batholiths: but the larger number of these batholiths are more recent than the mountains themselves. They have invaded the mountains surrounding them, but their effect has merely been to modify folds already formed. Such is the case with the massive granites of Erzgebirg and Devonshire.

Foundations of Mountains

Sometimes batholiths carried by the mountain have shared in its movement and have been modified by these mechanical means, so that the batholithic rocks have been transformed into gneisses and crystalline schists. Proof that this mode of formation characterizes the structure of the Alps has been afforded recently by the information which the borings of the Simplon Tunnel afforded to geologists. Great sections of mountains several cubic kilometres in extent, and constituted of rocks from the depths of the Earth, partially modified, were found to have participated in the movement which folded the mountain; they had been twisted to their roots, dragged and pushed as if they had been inert, by the force of those sedimentary strata which formerly formed their roof.

In other cases the form and distributions of the batholiths are in a measure dependent on the greater features of the structure of the mountains. Such for example are the granite batholiths of the middle Alps which extend from Giudicaria valley and from Adamello in the Tyrol to Bacher-

gebirg in Styria, and which divide two distinct mountain systems. In this instance the crustal movements were such as to permit the extrusion of these rocks from the depths, after the mountains had assumed their form and contour.

In the present state of knowledge we perforce admit that the granites and basalts ejected (as in the case of the spine of Mount Pelee) from a volcanic chimney, are made in the same subterranean magma as the batholiths. We imagine the batholiths forced up from the depths by the gradual fusion of the rocks surrounding them. Some batholiths never reach the surface: they remain mere intrusive rocks. In other cases when at a certain distance from the surface, and when the pressure on them is relaxed, the explosive forces within themselves and latent in their surroundings, become greater than the strata above them can restrain and a volcanic centre is established. It may burn through the overlying centre to form a volcano of one or other of the recognized varieties.

Although volcanic forces cannot give birth to mountains and are not in any sense mountain builders, nevertheless their distribution and their mode of action show a dependence on the character of the terrestrial surface which is in itself interesting. Whereas active volcanoes are absent from the comparatively recent mountain formations, such as the Himalayas or the Alps, one finds them most often in recent formations, and they often seem to be distributed along lines which have been determined by the process of mountain building. The great African volcanoes are exceptions to the rule; Kilimanjaro, Kenia, Teleki, and Koulalall near Lake Rudolph, as well as the Abyssinian and other volcanoes, are situated on fissures cutting across ancient and undeformed plateaus. The extinct European volcanoes such as those of Bohemia and Auvergne are chiefly distributed along old faults and displacements of ancient mountain ranges.

We have noted elsewhere a possible differentiation of

lavas erupted by volcanoes into those which are poor and those which are rich in silicates. To those poor in silicious acids belong the lavas ejected by the volcanoes of Africa, mid-Europe, and of the island volcanoes of the Atlantic (not however those of the West Indies). The West Indian volcanoes belong to the second class, those which are associated with "recent" mountain ranges and specially those which border the Pacific. These facts seem to afford good reason against the acceptance of the theory that volcanoes spring from isolated reservoirs of molten rocks; they rather lend force to the belief that the internal magmas are determined by the inner composition and structure of the planet.[1]

Mountain Building and Radio-activity

Returning to the question of mountain building, reference must be made to the increased complexity which has been added to the problem by the recent studies of the Alps. Something more than a wrinkling of the planet's crust has to be accounted for. Tangential or sideways pressure might crumple the crust into folds, as one might crumple this page by pushing it sideways, achieving by this means folds bending in more than one direction or overlapping one another. But the overlappings of the Alps are on such a scale that mountainous materials have been carried from the south of the Alps to the north, leaving them finally as mountainous ranges of ancient sediments reposing on foundations younger than themselves. It is as if some great earth tide had rolled the ancient sediments in a wave on to those that were unborn when the first rocks were laid down.

[1] Suess remarks that the Messina earthquake of 28 December, 1908, is a striking example of the absence of interdependence between volcanic and earthquake action. While it took place, Etna and the volcanoes of the Lipari islands remained quiescent. The great eruption of Vesuvius in April, 1906, was unaccompanied by any earthquake in Calabria and conversely the great earthquake shocks of 1905 had no influence on the neighbouring volcanoes.

"The lesser mountains which stand along the northern border of the great limestone Alps," says Joly [1] "—those known as the Préalpés—present the strange characteristic of resting upon materials younger than themselves." They are mountainous analogues of the boulders which glaciers carry, gigantic blocks which have been transported from the central zone of the Alps lying far away to the south. They are strangers to the locality where they occur; their materials may be dolomites, limestones, schists, sandstones or igneous rocks, but they all show signs of severe pressures and contortions. The igneous rocks can be traced to Mount Blanc, to the Tyrol, to the Italian lake mountains. . . . The Préalpés are in short mountains without roots.

"In this last-named feature the Préalpes [2] do not differ from the still greater limestone Alps which succeed them to the south. Such giants as the Jungfrau, Wetterhorn, Eiger are also without local foundations. They have been formed from the overthrown and drawn-out curves of great crust folds whose roots are traceable to the south side of the Rhone valley. The Bernese Oberland originated in the piling up of four great recumbent folds, one of which is continued in the Préalpes." The Préalpes are not an exceptional case [3] They are merely an example of the mechanics which have made the Swiss Alps what we see them. They are not a local shift of the sedimentary sheet of the Alps. Almost the whole covering has been pushed over and piled up to the north. The Préalpes have been cut off from the sheets to which they belonged by the action of denudation, but Lugeon thinks that if we could have examined them before they were thus separated from their roots, we should have found eight sheets of sediment superimposed and folded over. The sheets stretched as far as Mont Blanc and the Finsteraarhorn. It is as if one threw back the eight-fold

[1] "Radio-activity and Geology," by J. Joly (Constable, 1909).
[2] *Ibid.* [3] Lugeon, "Bulletin Soc. Geol. de France," 1901.

thicknesses of blankets on a bed. The uppermost of the superimposed recumbent folds is more extended in its development than those which lie beneath. Passing downwards from the highest of the folds, they are found to be less and less extended in the lower layers. Joly figures the arrangement in another way. Those folds which have their roots farthest to the south are most drawn out to the north. He is reminded of the breaking of waves on a sloping beach. The wave retarded by its base is carried forward at its top, and finally curls over and spreads up the beach. If it could be frozen as it spreads, the next wave must spread over it. So with the strata tumbled one over the other to form the Alps.

These phenomena [1] have drawn from geologists many explanations. Some like De Marchi have attempted to show that the assemblage of heavy sediments on the concave beds of the oceans would originate bendings and overthrusts, or underthrusts of strata, even as the strata were laid down. Joly calls in the phenomena of radio-activity to explain this most puzzling of all geologic problems. The sedimentary rocks could not have been so pushed by a sideways pressure unless they had been of a nature which made them flow when compressed; and Joly ingeniously demonstrates that they must have been of varying degrees of viscosity—like different thicknesses of treacle. Further than that he attempts to trace a connexion between this varying viscosity and the temperatures to which these underlying compressed rocks were subjected; and imagines a state of things in which the heat slowly rises towards the top layer of the folded and ever-folding rocks, while the rocks become ever more and more flowing.

For the source of the heat Joly does not rely on the interior magmas of the Earth: but on the amount of radium

[1] Lapworth nearly a generation ago called attention to similar phenomena on a smaller scale in the Scottish Highlands.

in the sedimentary rocks. Traces of radium have been found in nearly all surface minerals. There would be a concentration of radium in sedimentary rocks. Joly in considering the effect of the radium in the rocks disclosed by the borings of the Simplon Tunnel, with their unexpectedly high temperatures, came to the conclusion that it would be possible to explain the differences in underground rock temperatures by attributing such temperatures to the amount of radium the rocks contained. Thence he argued that local concentrations of radium brought about by sedimentation cause local increases of temperature in the planet's crust. At these places the resistance of the crust to strain, or stress, or thrust is weakened—and thus favourable conditions are furnished for the upheaving, and folding and overthrusting.

CHAPTER XIV

AGE AND CLIMATE

Radio-activity as a source of heat supply—Radium and the Earth's heat—Estimates of the age of the Earth—Climate of the early Earth—Glacial periods—Croll and the great Ice Age—Duration of glaciation on Mars—Glacial epoch of the Permian—Effect of distribution of land and water on climate—Atmosphere and climate—Variations in the Sun's heat.

IN March, 1903, Curie and Laborde announced the heat-emitting property of radium. They discovered that a radium compound continuously emits heat without combustion or change in its structure [1]; and that the heat emitted is sufficient to maintain the temperature of the radium 1·5° C. above its surroundings. Stating the fact in another way—one gramme of radium emits enough heat every hour to raise its own weight of water from the freezing to the boiling-point. After the lapse of 10,000 hours, enough heat has been emitted to raise the temperature of a million times the radium's weight of water one degree. We need not follow the process in closer analytic detail. It is evident that if radium exists in any appreciable quantity in the Earth's crust, or if processes of radio-activity comparable in any way to those which radium reveals are going on among the Earth's minerals, then the amount of heat thus released should have some important bearing on the structure, and even the constitution of the planet.

Radio-activity is certainly not confined to the radio-

[1] "Molecular Structure," P. Curie and Laborde, "Comptes Rendus," 136, p. 673 (1903).

active elements; but exists everywhere in a very small degree. The air of cellars and caves is radio-active; so are freshly fallen rain and snow; so also is a good deal of drinking water. Mineral springs and volcanic gases exhibit radio-activity; it has been found in muds and clays and rocks. In many of these cases the radio-activity has been traced to the presence of minute quantities of radium in the substances examined; and since radium is continually emitting emanations which themselves are changing and are dispersing rays in so doing, it is possible that the observed radiations in air and water arise from the energies of radium, its ancestors, or its derivatives. It seems equally probable that all substances are radio-active to a greater or less extent; and that a process is going on which quickly or slowly results in the unlocking of the energies of atoms. In the process of unlocking, the heat is one of the forms of energy which is made manifest.

Radium and the Earth's Heat

When these facts were appreciated no time was lost in fitting them to explanations of astronomical and geological problems. The maintenance of the Sun's heat has furnished a problem not wholly solved by the theory of Helmholtz, that the heat is supported by the falling together of the Sun's particles as it contracts. The solution is unsatisfactory, because the Sun on this theory would appear to have had too short a life. In Lord Kelvin's words it would be "on the whole probable that the Sun has not illuminated the Earth for 100,000,000 years and almost certain that he has not done so for 500,000,000 years. As for the future we may say with equal certainty that inhabitants of the Earth cannot hope to enjoy the light and heat essential to their life for many millions of years longer—unless sources of heat now unknown to us are prepared in the great storehouses of creation." . . . The phenomena

of radio-activity have pointed to some such unknown sources of heat. Helium exists in enormous quantities in the Sun; and helium is one of the products of radio-active elements. It is possible, and even likely, that large quantities of radio-active elements exist in the Sun. If there were 2·5 parts of radio-active matter in every 1,000,000 parts of the Sun's matter the heat given out would be sufficient to keep up the Sun's output of heat and light.[1]

Prof. Joly, as we have seen, drew attention to the importance of radio-activity as a source of earthly heat,[2] whether the radio-active minerals were abundant in the crust, or deeper down. Rutherford[3] calculated that if there were 4·6 parts of radium in 100,000,000,000,000 parts of the Earth's materials this amount would compensate for all the heat which the Earth radiates away into space. Finally Strutt,[4] and Eve[5] (in Canada) examined rocks of the Earth's surface, both igneous and sedimentary, and found that the amounts of radio-active minerals in them were much in excess of the quantity which Rutherford's calculations demanded. The quantity varied from 4·78 grams of radium in 1,000,000,000,000 grams of Rhodesian granite to ·3 grams of radium in 1,000,000,000,000 parts of Greenland basalt and ·12 parts to 1,000,000,000,000 of Cambridge chalk. Eve found the mean of these results to be 1·7 to 1,000,000,000,000 for igneous rocks and 1·1 for sedimentary rock; and both these results are more than thirty times as great as Rutherford's calculations require. Lava flows, and volcanic rocks and some igneous rocks show still higher proportions of radio-active minerals. Some

[1] Rutherford's and Soddy, "Phil. Mag.," May, 1 03; Wilson, "Nature," 9 July, 1903.

[2] Joly, "Nature," 1 October, 1903.

[3] $4·6 \times 10^{-14}$ grams per gram of the Earth's materials, Rutherford and Soddy, "Phil. Mag.," May, 1903.

[4] Strutt, "Proc. Roy Soc.," 77A, 472 and 7A, 150.

[5] Eve, "Phil. Mag.," August, 107, p. 231-

of the Simplon Tunnel rocks go up to the figure 9·6 per 1,000,000,000,000 parts; and the mean of a large number of igneous rocks other than the Simplon reaches the high figure of 4·2 per 1,000,000,000,000 parts, nearly a hundred times as great as is needed. If we were able to suppose that radium or radio-active minerals were equally distributed all through the Earth, we should then be faced by the extraordinary fact that these substances are giving out more heat than the Earth is losing; and therefore so far from the Earth's becoming cooler by loss of heat into space, it is becoming hotter.

When the investigations concerning the presence of radium were pushed into the depths of the sea it was found that sea water and the deep sea oozes contained radium in large amounts. Joly [1] calculates that in the waters of the oceans there are 20,000 tons of radium, and that 1,000,000 tons of radium are spread over the ocean floor. The concave basins of the ocean accumulate and concentrate radium and uranium and their products; and Joly suggests that in the great trenches—such as that which by the nature of the first distributions of continent and ocean was formed along the western coast of the Americas—the sediments there laid down gather not only matter but radio-active energy. "The energy is in fact transported with the sediments—the energy which determines the place of yielding and upheaval, and ordains that the mountain ranges shall stand around the continental borders. Sedimentation from this point of view is a conveying of energy." It will be seen that Joly substitutes for See's "steam action" the slow heat energy of radio-activity. We may conversely ask with See whether these radio-active phenomena are limited to a comparatively thin sheet of the planet's crust? Does radio-activity diminish with the depth of the crust?

[1] Joly, "Phil. Mag.," July, 1908, p. 190.

"So far," observes Joly,[1] "nothing definite on this point can be inferred. In parts the basalt of the Indian Deccan lava flow shows a small amount of radium, but the average is not lower than that of other rocks of the kind. The central St. Gothard rocks show the lowest radio-activities met with. . . . There may be significance in this. . . . But the whole question is at present hampered with the difficulty that we know but little as to the origin of the igneous rocks. We do not know the depths, from which they have been brought. . . ." It will be seen that radium's position as a planet-moulding influence is not yet assured; though even were the existence of radio-active minerals limited to a moderate depth of crust, their influence would be important, because the crust heated by them, like a self-heating blanket, would help to keep the core of the planet from losing its heat.

Age of the Earth

Viewed from this standpoint the potentialities of radium have been seized by geologists as an argument against that meagre limitation of the life of the Earth to which Lord Kelvin's mathematical theories led him. Lord Kelvin arrived at his estimates of the world's age from several considerations: the life of the Sun; the effect of tidal friction in retarding its velocity[2]; and the cooling of its rocks. He started with a globe 8000 miles in diameter with a uniform temperature of 3710° C—which was the lowest temperature at which its crust could solidify; and he asked how long it would take such a globe to cool to the temperature and to the apparent distribution of underground temperature which exist to-day. The answer to the question depends on the conductivity and melting-points of the

[1] Presidential Address to Geological Section of the British Association, Dublin, 1908.

[2] The second of these factors has been modified on reconsideration by Sir G. H. Darwin (Presidential Address, Section A., Brit. Assoc., 1886).

rocks. Lord Kelvin's earlier calculations led to periods of from 20,000,000 to 400,000,000 of years; but later, as he secured more trustworthy information regarding melting-points and conduction, his time-estimates dwindled, till at last (1889) he declared for 20,000,000 to 40,000,000 of years as the age of the Earth—and observed that the figure was more nearly 20,000,000.

Against this conclusion the geologists and biologists struggled for some time rather helplessly—in spite of the historic but specious rejoinder of Huxley to the mathematicians' calculations. Sir Archibald Geikie who was among the first to admit the propriety of restricting the demands of the geologists for extravagant periods of time—30,000,000,000 years was an estimate once claimed by one school of geologists—nevertheless could not admit as the basis of the time required for the accumulation of the known sediments of the globe, a period of less than 100,000,000 years. Sollas[1] assuming that the sediments were laid down much faster than Geikie supposes, arrives at 26,000,000 of years as the age of the Earth, which agrees very well with Lord Kelvin's estimate: but other methods of computation, such as ascertaining the amount of dissolved sodium in the oceans and finding how many million years it would take to arrive there from the land, give the higher values; and it may be said that, generally, geologists ask for 100,000,000 years as the limiting period in which the face of the Earth could have arrived at its present condition. It will be seen therefore that the prolongation of its years which the heating properties of radium may have effected, is a consideration of some value in reconciling theories. According to Rutherford, the geologists can now take as much time as they want.

Such an extension is of the greatest value to those

[1] Address to Section C., Brit. Assoc., 1900, p. 12 of reprint. See also address to the Geol. Soc. "Q. J. G. S," Vol. LXV 1909.

geologists who, like Geikie, still hold by the great principle first enunciated by Hutton[1] that "it is the little causes, long continued, which are considered as bringing about the greatest changes of the Earth". Hutton had little faith in great catastrophes and cataclysms as having brought about the mighty sculpture of the face of the Earth; the proper understanding of geology must, he believed, be arrived at by studying the things that are going on before our eyes, and by applying a consideration of their effects to the past of the planet, without substantial modification or alteration of their mechanism. He did not, however, observes Geikie, look upon time as a kind of scientific fetish to explain everything, and competent to make the most trifling causes effective in performing the greatest things "With regard to the effects of time," he said, "though the continuance of time may do much in these operations which are extremely slow, where no change, to our observation, had appeared to take place, yet, where it is not in the nature of things to produce the change in question, the unlimited course of time would be no more effectual than the moment by which we measure events in our observations."

There is another aspect of Hutton's teaching to which Geikie[2] has called attention. Far as he could follow the succession of events registered on the crust of the globe he well knew that behind and beyond the ages recorded in the oldest of the primitive rocks there must have stretched a vast earlier time of which no record met his view. The most ancient rocks that can be reached are very clearly not the first formed of all. They were preceded by others which we know must have existed though no vestige of them may remain. Hutton did not attempt to speculate beyond the limits of his evidence. "I do not pretend," he

[1] "Theory of the Earth," Vol. II, p. 205.

[2] Presidential Address to Geological Section, British Association, Dover, 1899.

said, "to describe the beginnings of things: I take things such as I find them at present, and from there I reason with regard to that which must have been." In vain could he look, even among the oldest formations, for any signs of infancy of the planet. He could only detect a repeated series of similar revolutions, the oldest of which was assuredly not the first in the planet's history, and he concluded "as the result of this physical inquiry, that we find no vestige of a beginning and no prospect of an end".

Climate of the Early Earth

First among the things to which it is wise to apply Hutton's philosophy is that of the climate of the planet. The state of mind which inclines to think that climate must always be changing finds popular expression in the phrases "old-fashioned winter" and "old-fashioned summer," from which we might inconsiderately infer that summer and winter have changed because we are not as old-fashioned as our grandparents. It can be shown that though the late Charles Dickens enjoyed a few snowy Christmases in his boyhood, yet during the greater part of his life they existed only in his novels; and any examination of diaries or other records in the fifteenth, seventeenth or eighteenth centuries shows that the climate of England has remained unaltered for several hundred years. Prof. Cleveland Abbe asserts that there is no evidence that the climate of any portion of the globe has materially altered in the last two thousand years. That there has been changes in the climate of the planet, and in its distribution, there is of course equally indisputable evidence to show; but the testimony afforded by coast erosion, or by the recession of Swiss glaciers, is misleading. Erosion of a coast line is often merely local; the advance and retreat of glaciers has been shown to be oscillatory over comparatively short periods, and to depend on a succession of wet or dry winters; while some effects

such as the cessation of vine-growing in Belgium, and in other parts of Europe, have resolved themselves on examination into effects due not to climate but to economic causes. Most of these so-called changes of climate appear to confirm the belief that any change at all has always been exceedingly slow; and is to be referred to those world-wide causes, undefined but irresistible, which, accumulating perhaps through millions of years, altered the shapes and configurations of oceans and continents.

Nor must it be hastily assumed that climate in past eras was more violent than it is now. In the effort to reconcile the slow deposition of the rocks with the curtailed estimate of the time in which they could have been deposited, suggestions were plausibly put forward, that all kinds of geological action were more vigorous and rapid than they are to-day, volcanoes more gigantic, earthquakes more frequent, tides and waves more powerful, tempests and rainfall more persistent. That may have been the case: but the rocks supply no evidence of it. "So far as the effects of denudation permit us to judge," says Geikie, "the latest mountain upheavals were at least as stupendous as those of earlier date.[1] They seem indeed to have been even more gigantic. It may be doubted, for example, whether among the vestiges that remains of Mesozoic or Palæozoic mountain chains any can be found as colossal as those of Tertiary times, such as the Alps. No volcanic outflows of the older geological periods can compare in extent or volume with those of Tertiary and recent date. . . . We seek for evidence of greater violence among the stratified rocks. Among the very oldest formations of these islands, the Torridon sandstone of North-West Scotland presents us with a picture of long-continued sedimentation, such as may be seen in progress now round the shores of many a mountain-girdled lake. In that venerable deposit the enclosed pebbles . . .

[1] Brit. Assoc. Dover, 1899.

have been laid gently down above each other, layer above layer, with fine sand sifted in between them . . . and so tranquil were the waters that their gentle currents and oscillations sufficed to ripple the sandy floor. . . ." Even in the most ancient of the sedimentary registers of the Earth's history, there is no evidence of colossal floods, tides, denudations. But there is incontrovertible proof of continuous orderly deposition, such as may be witnessed to-day in any quarter of the globe.

If, therefore, the records which can be examined yield no evidence of any great difference in the physics which shaped the planet, any theory which postulates another state of things in the eras before the sediments now accessible were laid down, must be received with reserve. One can say only in presenting these theories that the greater the period of time which we suppose to have elapsed since the planet became a cooling sphere the greater the aggregate of the denudation must have been, and the less possibility is there that the earliest rocks or sediments should have survived in quantity sufficient for identification or recognition. Whatever the method of formation of the planet may have been, it must have had a beginning, and it is reasonable to suppose that in the earlier stages of its growth the conditions were not the same as now. This is especially the case with regard to its climate ; for whatever hypothesis be adopted as to the way in which an atmosphere became attached to the planet, that atmosphere must have changed in composition and extent during the entire planetary history, a remark which also applies to the waters of the planet, and probably to the temperature of both. Evidences of local changes of climate due to these, or to some conditions, are found on every hand. The expeditions to the Antarctic have discovered fossil conifers, and while this may not be held to show that the South Polar climate was ever as warm as that of New Zealand, it certainly points to a period when

the conditions of vegetation were different from those prevailing there now. It is justifiable, without stretching probability too far, to say the same thing of the North Polar area; and, on the other hand, there are abundant testimonies to the fact that a number of times in the Earth's history, ice and snow extended southwards from the North Pole very much further than at present. The "Great Ice Age" which has been the battleground of so many theories, has resolved itself into a number of ice ages; and the areas which the ice covered in any one of them are far from being precisely defined; but there are evidences of ice at various periods in every region which we call temperate and in many which are called sub-tropical to-day.

Glacial Periods

In Europe there have been large glaciers invading the plains of France and Northern Italy; a succession of great ice sheets have submerged the lowlands of Roumania, Denmark, Belgium, Holland, Germany, and Great Britain. The Pyrenees, the Apennines, the Carpathians, the Balkans, the Urals, even the mountains of Corsica have had their ice sheets and glaciers. Nearly one half of North America has been buried in ice: though in one ice period it was not the whole northern half but the north-eastern half that was invaded; and the plains rather than the mountains. Alaska was partially free from ice except in the mountains in that epoch, there was less ice in the western plains than in the valley of the Mississippi while the greater part of four million square miles of ice field lay on the plains of Canada, and in the upper Mississippi valley. The Missouri and the Ohio embraced like two great arms the border of the ice fields to which they owe their origin.

In Asia ice fields far greater than any existing now stretched from the higher mountains and from Lebanon to the "frosty Caucasus". From the Himalayas to Siberia

and China: the lands adjacent to the Indian Ocean, at a period shortly after the carboniferous era, suffered a glacial visitation like that of recent geologic times in Canada. In Australia the coal seams are embedded with glacial drift. In Patagonia and New Zealand glaciers crept down from the mountains and covered the plains. Glaciers formed on the mountainous tracts of Tasmania and Australia.

Ice and snow have in short scored the traces of their presence in quarters of the globe where no theory of climate as we now know it will account for their presence. What used to be called "The Great Ice Age," and which was held to have existed comparatively late in the history of the rocks had a predecessor or predecessors millions of years before in the era of the Permian rocks. Therefore any theory which would account for the later epochs of glaciation must accommodate itself, more or less, to the earlier periods. Many theories have been propounded but none seems of greater significance than that which was due to Lyell, who urged that geographical changes in the distribution of sea and land would of themselves be sufficient to bring about the phenomena of a glacial period. A great continental area at the North Pole would for example bring about much colder conditions of climate in all the regions which are now called the northern temperate zones. Lyell thought that if the lands were massed towards equatorial or tropical latitudes the resulting climate of the globe would be such that genial conditions would characterize the polar regions. The land heated to excess would give rise to warm currents of air to sweep northwards and southwards to the poles. On the other hand, were the land to be grouped about the poles the reverse conditions would come about, for with no land at the Equator to absorb the heat of the Sun and to give rise to warm winds, the climates of the poles would become more severe and snow and ice would creep farther south. Lyell's proposition is illustrated by the present dis-

tribution of heat and cold on the Earth's surface. The lowest winter temperatures are experienced not in the North Polar region but in a large ellipse situated in North Siberia. Similarly the highest temperatures are not symmetrically distributed along the Equator but exist in patches on the great continental areas. A great expanse of land accumulates and intensifies extremes of temperature; the neighbourhood of a sea which in temperature neither rises above nor falls below certain levels, modifies these extremes. One perhaps might say that nearness to the pole is the warp, and land area the woof, of minus temperatures. Increase the land area of the northern hemisphere and it will grow colder. Increase the oceanic area of the southern hemisphere and it will grow warmer. Throughout recorded geological history there have been fluctuations of land and sea. It may be that each and every glacial epoch in either hemisphere is related to some fluctuations. The causes of these fluctuations are not known; they may be alterations in planetary surface due to the sphere's efforts to reach a condition of interior stability. They may be upheavals which occur not once a year or once in ten thousand years but which are slowly progressing over tens of thousands of years.

Croll's Theory

Lyell's tentative explanations were rejected as insufficient by the geologists who succeeded him:[1] and James Geikie preferred to hold by the then new theory of Dr. James Croll.[2] Croll's theory was that the glacial periods,

[1] "I have endeavoured to show (in respect of) this earth-movement hypothesis that no evidence is forthcoming to prove, as to render it probable, that the extensive elevations required have ever taken place, and that even if we could suppose them to have occurred, they would yet fail to account for the phenomena involved."—Dr. James Geikie, "The Great Ice Age," 1894 edn.

[2] "Climate and Time in their Geological Relations: a Theory of Secular Changes of the Earth's Climate," by James Croll (1890). See also "Climate

or as he preferred to call it, the climatic changes in the glacial period, resulted from the combined influence of the gradually changing tilt of the Earth's axis, and the gradually changing path of the Earth round the Sun. The path of the Earth round the Sun is not a perfect circle but an ellipse: and this ellipse sometimes approaches closer to a circle, sometimes becomes a more flattened ellipse. Both the tilt of the Earth's axis and the flattening and bulging of the Earth's path about the Sun, travel in cycles, that is to say there will be a period some 26,000 years hence when the tilt of the axis will be exactly the same as it is now, though it will have wandered in a cone considerably between now and then; and similarly there will be a period perhaps 50,000 years hence, when the Earth's path round the Sun will have about the same degree of ellipticity as at present though it will have deviated considerably in the shape of its path meantime. The time occupied in going round the ellipse is always the same: but the planet does not always hurry at the same pace.

Croll's argument was that if the Earth were travelling round the Sun in the most flattened form of its ellipse-like path and the southern hemisphere winter took place while the Earth was farthest from the Sun, then the present long frigid winter of the southern hemisphere would become still longer and the cold more intense. If on the other hand the northern winter (which now takes place when the Earth is nearest to the Sun) should, owing to the changing tilt of the Earth's axis, take place when the Earth was farthest from the Sun, then the northern winter would be proportionally lengthened, and its cold would be more intense.

James Geikie points out that the greater nearness of a hemisphere to the sun during the summer would not avail

and Cosmology" (1889), and the "Cause of the Ice Age," Sir Robert Ball (1893).

to free it from the effects of its long frosty winter—although in a period of great eccentricity the direct heat received from the Sun might be much greater. Although the rays of the sun in North Greenland will melt pitch in the seams of ships, the summers are extremely cold. The reason for this is that there is no radiation of heat from ice-covered ground, which absorbs all the heat poured on to it. Thus in one of Croll's glacial periods the summers would be cold, and though there might be increased evaporation, the result of the evaporation would be the production of fogs, which would only serve to cut off more of the Sun's rays. Even summer rain would be ineffective to wash away the snow and ice of the long winter. We may, in fact, sum up Croll's hypothesis by saying that according to his arguments, glacial periods were the result of some thousands of years of long winters and short summers in one or other hemisphere. The long winter was produced in one or other hemisphere, when the winter of that hemisphere took place while the Earth was at the farthest stretch of its eccentric orbit from the sun, and was travelling over that portion of its path at such a rate that the hemisphere's winter was about a month longer than the average. In the other hemisphere under these conditions, summer was about a month longer, the winter milder, and short, and the climate of about the geniality of an English spring. It will be evident, from these considerations, that a glacial epoch could not have existed in both hemispheres at the same time. While one had a glacial period, the other should have had an inter-glacial period. The artificial nature of the hypothesis becomes evident from the foregoing statement of it. Too little is known of the varying glacial epochs to enable a test to be made of this assumption, which, if proved to be fallacious, would invalidate the theory; and some doubt is thrown on it at once by the undenied fact that the epicentres of several of the areas of glaciation were not polar. In some cases the

glaciation in the northern hemisphere spread *to* the north pole. Thus there was an epicentre of glaciation in Norway and another in Scotland; there were several similar areas with their centres in Labrador (54° N. lat.); Hudson's Bay (62° N. lat.) and starting from the Cordilleras on the Pacific coast at a point about 58° N. lat. Kilimanjaro and Ruwenzori on the Equator itself were once much more glaciated than is the case now. It is not easy to see how to adapt a theory of cold produced by orbital eccentricity to mountains that are midway between the two hemispheres.

Glaciation on Mars

Prof. Lowell of Flagstaff, has assailed Croll's hypothesis from another point of view. It so happens, he points out,[1] that the astronomic conditions affecting the Earth several thousand years ago are in process of action on Mars at the present time. The orbit of Mars is such that its present eccentricity is greater than the Earth ever can have had; and the midwinter of its southern hemisphere falls when the planet is nearly at its farthest from the Sun. Here, then, are the conditions for a glacial period in the Mars Antarctic region. We should expect to find a southern polar cap which should not only be larger in winter than the northern polar cap in *its* winter, but which should not show an equal amount of dwindling under the influence of summer. But Lowell shows by maps of the Martian polar caps that this is far from being the case. The southern cap outdoes its northern counterpart in winter, as one would expect it to do, and there is a far greater stretch of Antarctic snow or hoar frost, than in the Arctic regions. But so far from excelling the northern ice fields in summer, which would have to be the case to produce permanent glaciation, it so far falls short of its fellow, that on the last occasion when it would be well observed, the southern cap

[1] "Lectures before Massachusetts Institutes of Technology." Republished in the "Evolution of Worlds" (Macmillan), 1910.

disappeared altogether though the northern cap did not. "The short, hot summer, then, far exceeded in melting capacity that of the longer, but colder one." Lowell's views are shared by Camille Flammarion—"the theory of secular variation of terrestrial climates caused by eccentricity of the Earth's orbit, which was proposed by Adhemar and enlarged by Croll on other grounds, is not confirmed by an examination of Mars".

One objection to illustrations from, and comparisons with Mars, is that the conditions of snowfall or rainfall, or deposition of hoar frost on Mars at the present time, are altogether different from any that have been experienced in the geological history of our own planet. The temperature of Mars is a matter of dispute, and so are the heat-retaining properties of its atmosphere. Lowell is disposed to rate all of these at a higher value than other observers of Mars; and he scouts the proposition put forward by some theorists that what is to be seen about the polar caps of Mars is carbonic acid snow rather than frozen water vapour. He points to a broad blue band about the dissolving polar cap of Mars in spring, as proof that here is melting ice or snow, and not solid carbonic acid which changes directly from the solid to the gaseous state without interposition of a liquid stage. He has also affirmed the presence of moisture on Mars on the evidence of the spectrum. At the same time, as one of his critics, Mr. E. W. Maunder,[1] of Greenwich Observatory, points out, the polar caps on Mars diminish with a speed and to a degree utterly in excess of anything that takes place with the corresponding terrestrial caps. The explanation may lie partly in the length of the Martian summer, partly in the small amount of moisture on the planet, and therefore in the thinness of the polar deposit, but chiefly in the readiness with which the snow once melted would pass into vapour and be carried towards the Equator.

[1] "Knowledge," March, 1910.

Lowell, however, does not limit himself to destructive criticism. He offers a solution of the glacial problem, which is that the prevalance of ice and snow was due not to alterations in the length of winter and summer, but to a larger snowfall. "The amount of snow which a summer of given length and warmth can dispose of is, roughly speaking, a definite quantity. If, then, the snowfall in the winter be for any reason increased daily in both hemispheres, a time will come when the deposition due to the longer winter of the one will exceed what its summer can melt relatively to the other, and a permanent glaciation will result in the hemisphere so circumstanced. Increased precipitation then, not eccentricity of orbit, is the real cause of an Ice Age." But what are the causes which will produce increased snowfall and rainfall? Lowell pictures the Earth as at first surrounded by a blanket of clouds. 'Clouds would let little solar heat in, but they would prevent its radiation, so that early in the world's history the climate was much more uniform, and it might be described as one dull perpetual round of rain. But as the temperature of the seas began to fall, the clouds began to clear. Variations in climate also appeared; evaporation went on much less fast but there was still a great deal of precipitation of moisture, snow in winter, rain in summer; and this joined to the elevation of land areas produced glacial epochs.'

The solution of the problem is far from being as simple as that, though geology is indebted to Prof. Lowell for his illustration from Mars of a flaw in the Crollian argument. If we were, however, to adopt Lowell's constructive hypothesis we should have to picture the Earth as awakening to the existence of a shining Sun only after the time when the tree-ferns of the Carboniferous times were laid down. Until then the Earth was wrapped in deep gloom or semi-obscurity, and "the climate was warm and equable over the whole globe because a thick cloud envelope shut off the Sun's

rays, the heat being wholly supplied from the steamy seas". But evidences of glaciation have been found in the Cambrian rocks which were laid down ages before the Carboniferous forests and swamps made their appearance. Carboniferous strata themselves are interspersed with evidence of glacial epochs. After the Carboniferous period came the Permian period; and this period presents not merely relics of widespread "glacial epochs," but it shows that portions of the globe were subject to the most intense aridity; that deserts as conspicuous as any now known extended over great areas of the planet. After the glacial periods of the Permian epoch follow other successions of strata, indicating the lapse probably of millions of years—before the advent of the Pleistocene period, and of those great Ice Ages, the marks of which first drew the attention of geologists to the evidences of immemorial glaciation. From these evidences we must draw the conclusion that while the climate of the globe is a thing which must have been the product of evolution, and which indeed must still be changing (though the evidences of change are imperceptible), yet the record of its progressive change is not stamped either in fire or frost on the rocks. There have been glacial periods, separated by millions of years in time. There have been periods when desert areas were as marked as they are to-day. There is no evidence of an increasing aridity on the globe; and the theory that the globe once had a far greater rainfall, which is now progressively diminishing, is one that is uncertainly based on inference.

The Permian Ice Age

There are relics of glaciation, as we have said, among the earliest of the sedimentary strata (Cambrian in Norway, and in China), but the glaciation of the Permian period which brings the first great geologic division of the rocks, the Palæozoic, to a close, is that which provides the most

puzzling of climatic problems. The Permian period was otherwise remarkable for a remarkable shifting of geographic outlines, and for great foldings of the Earth's crust. It is hardly possible not to suppose that at this epoch there was a great lessening of the area occupied by the oceans, and a great upheaving of continental land, accompanied by great deepening of the ocean beds. It is possible to suppose that previous to the Permian the globe had been suffused with a damp cloudy atmosphere, and that the seas were warm. Such conditions would fit in very well with the formation of the vast vegetable deposits of the Carboniferous era, though, as Eliot Blackwelder[1] observes: "We can hardly reconcile with the hypothesis of a perpetually damp cloudy atmosphere, the existence of deserts in India in the Cambrian period, in New York in the Silurian, in Michigan and New Brunswick in the Carboniferous, and in Germany in the Permian period. Yet the testimony of the rocks is emphatic that they did exist in those times and places."

It becomes increasingly clear that while we may imagine the Earth's climate to have been subject to a gradual change, and while the records of the rocks leave us in no doubt that the conditions at any point on the Earth's surface have been subject to almost as great variations of climate as of level, yet that no one theory of diminishing warmth, of diminishing cloudiness, of increasing or of diminishing ocean surface will cover all the cases. We may believe, indeed we are as well assured that the climates of Europe and Asia and America have changed, as that their areas have been successively submerged beneath ocean waters and subject to the encroachment of desert. But the rocks, so far as they open their historical pages to scrutiny, reveal an oscillatory change rather than a progressive development, whether the change be in climate, in aggregation, in denudation, or in submission to volcanic and tectonic moulding.

[1] "Science," April, 1909, p. 660.

Land, Water, and Climate

That Permian period of which we have just spoken is a crucial period in early geologic history, because it assembles so many problems and makes necessary so many assumptions in order to explain them. It is assumed, for example, that previous to the Permian period the Earth had been passing through one of its quiescent stages, when there were, in the northern hemisphere at any rate, few crumplings of the surface, when continents were rather flat and climates rather equable. During this period of calm, the Earth may be supposed to have been gradually accumulating in its body those stresses which were to overthrow the monotonous quiescence, and to replace it by a period of activity which was actually as well as figuratively volcanic. The period of waiting may have been ages long; the period of change, when the revolutionary forces at length gathered sufficient intensity to set it in motion, may have been equally long; and the changes may have not been sudden but may have merely gone slowly forward till the stresses were relieved and the Earth was prepared, as Matthew Arnold said of the brooding East, to plunge in thought again.

Secondly, it is assumed that the essence of the movement was a deep-seated shrinkage of the Earth which tended to disturb the balance between the oceans and the continents. This provoked crumpling and mountain building; a rise of the continents, a deepening of the oceans; a withdrawal from the continents of vast sheets of water; the drying up of 20,000,000 to 30,000,000 square miles of shallow seas. This would materially restrict and alter the circulation of the oceanic waters; and this alteration would profoundly modify the climate of the times. It is possible, nay it seems likely, that in the calm Carboniferous era, the seas were warm, and the oceanic circulation was such that the pole was

bathed in water which helped to maintain a comparatively mild temperature. The maintenance of this warmth may have been abetted by a heat-retaining atmosphere, heavy with cloud, and containing a good deal of heavy carbonic acid gas. When the circulation of the waters was interrupted, one cause of the maintenance of a comparatively warm equable climate in the north was withdrawn.

Other consequences of the alteration of sea and land came into operation. As the surfaces of shallow seas were exposed the atmosphere began to act on the new surfaces. We are not bound to suppose that either the air or the sea were identically the same in constitution then as now, though the fact of the conditions of glaciation in the Cambrian, the evidences of the aridity in the Silurian, and of life in both, forbid us to assume that they were radically different. An assumption that will help to explain both the climate of the quiescent stage, and of the stage which followed it, is that whereas in the first the oceans began to lose their carbonic acid and their carbonates and the air grew richer both in oxygen and in carbonic acid—in the second or upheaval stage the air began to part with its carbonic acid and its oxygen to the new lands with which it now came into contact.

Atmosphere and Climate

This was not the only effect felt by the air. The interruption of the water circulation and the growth of lands contributed each in its way to differentiate the globe into hot and cold regions. Winds arise, at any rate in part, from the unequal heating of land surfaces; and a more vigorous air circulation would intensify climate. Moreover, as the moistness of the atmosphere, following the carbonic acid and the oxygen, began to diminish with the growing area of the land, the blanket-like action of the water vapour in retaining heat would lessen. The effect would be more

apparent over land than over sea; and another source of differentiation would thus arise. Each of the assumptions we have named leads to the conclusion that when a period of land domination followed one of ocean domination on the planet, the equable climate preserved by the oceans gave place to extremities of climate ushered in and fostered by the land surfaces. It is possible that when the planetary equilibrium was disturbed, either in respect of its distribution of land and sea, or in its distribution of heat and cold, or in its interchange of gaseous constituents between sea and land—that the oscillation did not pause on any condition of rest, but became excessive in the contrary direction, as a pendulum altered from a position of rest swings beyond that position in the reverse direction before rest is restored. Prof. Arrhenius has suggested, for example, that a burst of volcanic activity coincident with rising continents would furnish the air with great supplies of carbon dioxide.

Such are some of the explanations of one glacial period, and though they are not competent to explain the later glacial periods in geologic history, they suggest some of the causes which may be common to both, and which are,—disturbance of the oceanic circulation in the first place and disturbance of the atmospheric circulation in the second. Both these are intimately dependent on the distribution of land masses and sea areas. There is a growing disposition to refer weather, if not climate, principally to the atmospheric rather than to the oceanic circulation. This point of view was not ignored by Croll, who urged that the conditions he described might cause a few degrees shift southward of the Trade Wind belts, which in consequence would alter the directions of the equatorial ocean currents.

Meteorology has during the past generation recognized certain permanent areas in the atmospheric ocean where a cyclonic region or an anticyclonic region is permanent or semi-permanent. There are, for example, permanent areas

of barometric pressure which influence the seasonal character of the weather in the Antarctic or in India; and there are semi-permanent areas in the Atlantic which have their influence even on the unstable summers and winters of Western Europe.[1]

W. N. Shaw[2] has shown that connexion exists between the velocity of the Trade Winds in one year and the temperature of the North Atlantic in the next. Lockyer has shown reasons for believing in the existence of a kind of see-saw in barometric readings at points opposite to one another on the globe. From these observations the inference is a tempting one, that a type of atmospheric conditions may have been induced by the configuration of land and sea, such that there were permanent cyclonic areas far south, which were fed from the poles with cold moist currents. At these points moisture was precipitated at sufficiently low temperatures to promote the formation of snow and ice; and the continuance of such causes and effects, added to others which we have indicated, may have led to glaciation.

Variations in the Sun's Heat

These hypotheses nearly exhaust the explanations offered, though it has been suggested that the glacial eras might have been caused by variations in the Sun's heat. Dr. C. G. Abbot[3] has shown that there is a variation amounting to as much as 5 per cent in the heat received from the Sun: but no proof, of course, is possible that there were intermissions or lessenings of the Sun's heat extending over the tens of thousands of years which glacial epochs covered.

In summary, one may say that theory inclines to attribute climate to alterations in the distribution of sea and

[1] Douglas Archibald, Paper read before Section A, British Association, on "Weather Types" (Clifton, 1898).

[2] Presidential Address, Section A, British Association (1908).

[3] "Astrophysical Journal," Vol. XIV, 1904, pp. 305-21.

land; and that these alterations may be referable to the deep-seated efforts of the globe to attain equilibrium; or in a lesser degree to the changing content of the ocean basins and land masses.

A great alteration in the relative areas of land and sea would alter the constitution both of sea and of air, by affecting the interchange of gases between them. There would be an oscillation of the relative quantities of carbon dioxide and of oxygen occluded in sea and atmosphere.

This cause, added to the revised distributions of land and sea, would lead to the formation of new currents both in the ocean and in the atmosphere.

These new conditions would disturb climate and would tend to differentiation of temperatures; perhaps would produce new and permanent areas of low or high barometric pressures. These in their turn would produce semi-permanent conditions of temperature within or about their areas. The present exceptional glaciations of Alaska or Greenland are within permanent cyclonic areas.

Any or all of these effects being prolonged in one direction would give rise to a reaction in a contrary direction. For example, assume a condition of equilibrium between the carbonic acid gas in the air and that absorbed in the ocean. When the sea area began to diminish and the land to spread, the air lost some of its carbonic acid by combination with the exposed surfaces. It, therefore, drew upon the ocean. But when glaciation set in all the land surfaces were covered with ice, the carbonation of the rocks ceased and the air again became charged with an excess of carbonic acid gas. It thereon began to assume a greater heat-retaining capacity once more; and the conditions producing glaciation would by so much become modified.

CHAPTER XV

THE INFLUENCE OF LIFE

Strata and the succession of life—Uniformity of geological history—Persistence of conditions—Periods of geographic activity and quiescence—Mutations of species—Life and the physics of the Earth—Pedigrees of life and of the strata—Earlier relics of life.

IN the ninth edition of his "Principles of Geology,"[1] Lyell remarked that "no satisfactory proof had yet been discovered of the gradual passage of the Earth from a chaotic to a more habitable state". That extreme assertion of the doctrine of uniformity is, if taken literally, equally true now. There are apparent breaks in the succession of the rocks, but the gaps are filled in with each new discovery, and it is imaginable that when the face of the whole Earth has been examined with the regularity and thoroughness which geologists have given to European strata, an unbroken pedigree of the wcrld's epochs may be revealed to show that the Earth history has pursued an even course, uudisturbed by any world-wide catastrophe, since the first strata were laid down.

Lyell, however, went further. The great generalization of Darwin was then unfamiliar, and Lyell though acquainted with it, was yet ready to assert, in continuation of the phrase already quoted "nor . . . has there been discovered . . . any law governing the extinction and renovation of species, and causing the fauna and flora to pass from an embryonic

[1] "Principles of Geology," 9th ed., p. 146.

to a more perfect condition, from a simple to a more complex organization. . . ." That is where the new geology joins issue with the old. There may be uncertainty as to the development and growth of the crust of the planet, but we are assured of a law of progressive development in the life of the planet.

Lyell was well aware, as were geologists before him, of the value of remains of plants and animals in the strata as a means of determining the age of the strata. The strata that are uppermost are indisputably later than the ones underneath, if both are undisturbed; and in the earlier days of geology it was found that the uppermost beds contained organic forms either identical with those now living or very nearly similar to them; while beds lower and lower down contained fossils which departed more and more from living types. The strata, therefore, were the first indication that there was a general order of life succession.

The second discovery was that this succession of life was in its main features the same for all the continents where the strata were examined. There were different animals and plants in different portions of the world in the past eras where life was disclosed by examination of the rocks; just as there are different species now. There were shiftings and migrations; and seeing that every prehistoric period thus examined was very much longer than the historic period of our knowledge, it was evident that in those periods the increase of given species in some regions, and their dying out in other regions, would be more marked in the record than similar occurrences now. Many other complications enter into any examination that can be conducted of the life of these past periods. But through all of them run a sufficient number of common features to show beyond reasonable question the order of the succession of life. The first and chief guide to the study of the *succession of life* was then the order in which the strata were laid one on another,

It is a study which is still progressing, and which each year adds something to biological knowledge.

But now that the succession of life has become an axiom, and the progressive development of species a truism, the study of life-forms renders back to the study of the strata some of the debt it owes; so that now, if a geologist should seek to determine positively the period to which deformed or displaced strata belonged, he would refer to the fossils of the strata for evidence and information.

"While stratigraphy was thus, in the earliest stages," observe Chamberlin and Salisbury,[1] "the main reliance in determining the order of events, and biology was the chief gainer, in the end stratigraphy received ample compensation, if it did not become the greater beneficiary; for at no known and accessible place is there a complete succession of sedimentary beds. There are great series here and there, but their connexions with one another are more or less concealed by surface formations or bodies of water. So also at many places the stratified series has been broken up by deformation, or cut away by erosion. Hence there was need for some trustworthy means of matching the beds of separated series, and of making up a complete ideal series. This means is found in the fossils they contain. While the variations and migrations of life-forms in different regions offer some difficulties, the relations of the fossiliferous beds of one region to those of another can be determined with great satisfaction, and often with great precision. This is particularly so when abundant floating or free-swimming species lived in the seas and were freely fossilized, for they were deposited in the coasts of all continents at practically the same time, and no uncertainties arising from migration or local differences in the rate of evolution intervened to throw doubt upon the correlation." Without the aid of

[1] "Geology and Earth History," Vol. I.

fossils the task of relating the deposits on one continent to those on another in point of time, would be so difficult as to be nearly impossible.

Uniformity of Geological History

Thus for logical purposes the history of the strata is the history of the life in them. The history of the life-forms is a matter of observation. The history of the strata, apart from the life-forms shut up in them, is often a matter of inference. The inferences have changed a little since Lyell's day. Lyell, although he was late to support Darwin's generalization that all changes in species came about by the accumulation of minute differences, had laid down an almost identical principle in the uniformitarian doctrine of geological development—namely, that every change in the Earth's surface was brought about by causes similar to those in operation to-day. It was a doctrine vigorously criticized by the geologists of his day, even by Adam Sedgwick, the last of the able advocates of the Catastrophist School, who observed, "Though we have not yet found the certain traces of any great diluvian catastrophe, which we can affirm to be within the human period, we have, at least, shown that paroxysms of internal energy accompanied by elevations of mountain chains, and followed by mighty waves, desolating whole regions of the Earth, were part of the mechanism of nature".[1] The gradual evolution assumed by Lyell has superseded the catastrophes which Sedgwick was so reluctant to abandon. But the physical doctrines of the alterations in the face of the Earth have changed in the last generation, and are changing now. What may be described as the uniformitarian theory of slow change has been enlarged by the idea of cyclical change. It is very

[1] Quoted by Sir A. Geikie in the Rede Lecture, "Darwin as Geologist" (Camb. Univ. Press), 1909.

well stated in an address by Prof. Bailey Willis of the University of Chicago.[1]

Persistence of Conditions

According to this statement of principles :—

Ocean basins are permanent hollows in the Earth's surface, and have occupied their present positions almost since the date when the planet first acquired geographical features. There have, however, been notable changes in their areas and the position of their margins, due to the encroachment of the oceans on the continental areas.[2]

On the surface of the permanent oceans the chief currents and system of circulation have also persisted since the earliest times, and are similar to the currents which now follow the Trade Winds. The present *deep circulation* of the oceans, which flows towards the pole nearer to the surface, and towards the Equator lower down, is due to the exceptional refrigeration at the pole.

The great crustal movements of the Earth have been periodic. From this point of view the Earth's history falls into cycles, and each cycle into two periods, one of inactivity and another of activity. The periods of inactivity have been long and during the greater part of the duration of any such period the condition of inactivity has been common to the entire surface of the globe. But the periods of crustal activity have been relatively short and have not taken place at the same time all over the globe's surface.

The great ocean basins (for example) are provinces to

[1] Address to the Geological Section, American Association for the Advancement of Science, Boston (1910).

[2] It should be noted that Suess in his "Face of the Earth" does not appear to assent to this proposition. He says: "The high pedestals on which our continents rest may be very ancient; they may even date from the Mesozoic period, but for the Palæozoic period it would be impossible to maintain the theory of generally persistent continents." Further references will be found in Chapter XVI.

themselves; and each has experienced periods of crustal activity peculiar to itself and its individual history. Mountain folding and upsets of strata are frequently not contemperaneous even in the same great segment of crust.

Erosion, and sedimentation, or chemical separation of the rocks, or the evolution of life-forms, have been altered by the onset and duration of great crustal movements. But while erosion, like the other processes, may have been quickened or delayed, it has always been in progress and always has left its mark. Marine sedimentation has sometimes been inconstant. During periods of crustal activity when lands have been high and shallow seas small, and the ocean currents have been confined within deep ocean basins, then there has been great sedimentation. But in the long periods of crustal inactivity when the lands have been low, the shallow seas encroaching on them large, and marine currents have found their way everywhere, sedimentation has fallen off either because of scour, or because the sediments decreased in quantity.

Evidently these views call for an adjustment of the theories of the progression of life. Perhaps one might not unjustly say of the most obsolete of geological theories that it pictured the development of both the structure and the life of the globe as taking place in a series of jumps. There was a jump from the period when the rocks were igneous and contained (on that account) no traces of life, to the period when with the Cambrian rocks the first well-defined forms of life were found to be abundant. Then there was a break, caused by some undiscovered catastrophe in the Earth's history, and the Silurian period began and continued with another series of forms of life, of which some were related to ancestors in the Cambrian, but some, and these were higher forms, were new. Then another break; and another epoch, with other, and newer, and more advanced forms of life. Before Darwin, geologists were fain to imagine that with each

new epoch, life or—shall we say?—the newer and higher forms of it, were re-created for the new departure. With Darwin's modification the theory became far simpler. Each new form of life, however characteristic it might appear to be of any epoch, was but a descendant of some ancestor in the previous epoch. The steps of the descent had been lost; the missing links had been obliterated. Possibly because missing links were of the nature of transitional forms, and therefore of a more ephemeral character and of less widely distributed numbers than forms which were exactly suited to new environments. Possibly they exist still as fossils but are undiscovered. After all, fossils are mere scattered episodes in the history of life, and their permanence often no more than a happy accident. Darwin anticipated that with the progress of research some of the gaps would be filled up. It was an expectation in which he had the stronger faith because Lyell's theory of the gradual unchequered growth of strata removed the possibility that the whole life of an epoch, or a very large part of it, had been overwhelmed or removed by any world-wide catastrophe.

Periods of Activity and Quiescence

If, however, Lyell's theory is only part of the truth, and if the globe without being whelmed in catastrophe, is nevertheless subject to some such great crustal movements as have been indicated, if it suffers almost world-wide alterations of climate, and if the periods of its geographic activity and quiescence are different in duration and have differing effects on such processes as wearing down strata or building up strata, then we should expect the processes of life and of its development to alter. For example—though be it said that there are many followers of Darwin who are not prepared to admit these speculations—in a period of geographic or geologic activity the tendency on the part of some form of life to assume a different form might be hastened.

In a period of geographical quiescence the change might take place at a different rate. If, for example, some group of nearly related organisms dwelt for thousands of years in the same environment, with the same food, the same temperature, the same needs and the same dangers, it would not alter very rapidly or very much. If, on the other hand, it dwelt in a period when climate or the configuration of land and sea or the directions of ocean currents were altering its mode of life, then it might be forced to adapt itself quickly to new circumstances, or perish. Those of its race which did not perish would be these which had altered their constitution and structure. Or again, an organism confined within comparatively narrow boundaries, like a lake or an island, might remain little unaltered. But a complex organism, like an elephant or a horse, which had the freedom of a continent, might under novel conditions and climate reveal a capacity for alteration and expansion hitherto latent.

Thus even if one begins by submitting that Darwin's theory of change is the only one, and that all progress in life-forms depends on response to environment and the selection of individuals which each are a little better suited by the conditions surrounding them than are their neighbours, we are faced by the probability that change has not gone on in all ages and in all places at the same rate. But the problem will become immeasurably complicated if we suppose, with some geologists, like Dr. A. Smith Woodward,[1] or with botanists like Prof. De Vries,[2] and Mendelians like Prof. Bateson,[3] that the modifications induced by environment are not the sole cause of the variation of species.

[1] Presidential Address to Geological Section, British Association, 1909.

[2] References to "The Mutation Theory," by Hugo De Vries, translated by J. B. Farmey and A. D. Darbishire (1910, Kegan Paul).

[3] Mendel's "Principles of Heredity," by W. Bateson, F.R.S. (Camb. Univ. Press).

Mutations of Species

We must be satisfied with the most cursory statement of the theories of Mendel, De Vries, and Bateson. If we were to take a million red beans and grade them in any way—according to redness, or roundness, for example—we should find all kinds of redness, extending from pale pink to deep crimson, and all kinds of roundness. Between the extremes there would probably be such gradations of colour or shape as to make these extremes appear quite unrelated to one another. Darwin imagined that if two pale pink beans were crossed by chance, then that the resultant offspring, being also palely pink, would survive if pale pinkness were suited to its surroundings. But he made no attempt to say why some beans (of the same species) should be pale pink and some deep crimson. He postulated change as becoming established by the accumulation of minute variations, but he did not account for the minutest variations. The Mendelians do attempt to account for minute variations in a species. They say that pinkness or roundness in the bean (or to take a more familiar illustration, greenness or yellowness in the pea) depend on certain factors of heredity ; that yellowness or greenness is a definitely inherent character in the germ-plasm of the pea ; and that according to its properties so will it dominate the characteristics of the offspring of the pea. In short, they attempt to furnish some explanation of the minutest variations of the pea, and to find a law which will determine whether these variations shall be characteristic of the future generations of the pea. In their ultimate inquiry they may endeavour to ascertain what arrangement it is of the minute cells of the pea which favours persistence or change. These views are shared, in part at any rate, by Prof. De Vries,[1] whose name was first associated with the "Mutation Theory," by which a variation in a life-form, of a plant or an

[1] "The Mutation Theory," by Hugo de Vries (Translation), Kegan Paul.

animal, was conceived as arising not always by slow degrees of suitability, but suddenly. Being suited to its environment their new form continued and flourished. and became established. Thus the species might proceed by rapid mutations; and in the lifetime of a species there would be periods when it exhibited a tendency to change or mutation.

This is not very different from the attitude taken up by Dr. A. Smith Woodward,[1] and other palæontologists: that there is a persistent progress of life to a higher plane in the successive geological periods and that there is some principle underlying this progress much more fundamental than chance-variation or response to environment.[2] There are in the life of species sudden fundamental advances which an American naturalist, Prof. Edward Cope, called "expression points"; and in which he saw the manifestation of some inscrutable inherent life-force. The comparison with the rhythmic movements of the Earth's crust suggests itself. There are changes towards advancement, and towards fixity of type, alternating with changes towards extinction.

The course of these changes is hindered or modified by environment and natural selection—but it goes on. Most lifeless matter, inorganic solid matter, tends to organize itself in the form of crystals. In the world of life matter tends to organize itself in the form of cells which are not geometrical in form. In the inorganic world matter is chiefly crystalloidal and in the organic world it is chiefly colloidal[3]—though there are colloidal states of matter and

[1] Presidential Address, Geological Section, British Association, Winnipeg, 1909.

[2] "However much these phenomena may have contributed to minor adaptations."

[3] Among colloids are included all the plastic elements of animals and plants—that is, the various protein compounds. No hard and fast line however separates the colloids from the crystalloids. Although multitudes of bodies exist which may be placed in one or other class, multitudes of others are to

crystalloids among the organic products. Dr. Smith Woodward has compared the changes in the life of a species to the changes in the growth of a crystal. He imagines the crystal to have been disturbed by some impurities during its growth, so that it has become fashioned with unequal faces or has become even a mere lump. The inherent forces in the crystal have, even in its disturbing environment, been striving to arrange its molecules in a fixed geometrical shape. In the case of a chain of life each successive animal is a mass of colloidal substance grouped round its colloidal germ of life. The inherent forces in the germ of life (or germ plasm) are always struggling not to arrange the body growing round it in geometrical faces, but in various other symmetries. When the extreme has been reached, and the aim of the life-force is reached, the species rests, its activities cease, the race dies.

That is perhaps a fanciful illustration of the life of species, but it will be evident that whatever its truth or value, the observations on which it is based put out of count the simple hypothesis that since the beginning of life, development has gone on in a regular and direct manner, such as might be associated and compared with the equally regular direct and simple progression of the rocks. Even if the case be stated in its simplest form—that the growth of the strata of the Earth's crust has proceeded in cycles, and the development of life has proceeded in cycles, there is little reason for supposing that these cycles are contemporaneous or are related except in the most complex way. Geologists are beginning to discard the ancient divisions of the rocks as artificial; the genealogies of life-forms as revealed by the rocks is shown in some cases to be equally invalid. It is safer to proceed without any as-

be met with having properties of an altogether intermediate character. The colloids are supposed to be generally characterized by the large-sized complexity of the molecules of which they are compounded.

sumptions of precise relations between the geographical and biological developments of the successive epochs, and to inquire merely how each may have affected the other.

Life and the Physics of the Earth

In its simplest form, protoplasm, the stuff of which life-forms are made, exists as a jelly-like, slightly granular, semi-fluid substance, without visible structure, though it is presumed to have an excessively minute sponge-like or foam-like character, and to be capable of absorbing dissolved matter from without, as a preliminary process leading on to assimilation and growth. The principal foods which it assimilates are the compounds of carbon, of which carbonic acid is the chief; and these are followed by oxygen and hydrogen and other compounds which the life-form requires in the greatest quantity, and by nitrogen.

All these are constituents of the atmosphere. We may say that the chief material of life comes from the atmosphere; or that life and the atmosphere are interdependent. There are, however, many other elements than those of the atmosphere, such as sulphur, phosphorous, silicon, iron, calcium, chlorine, potassium, sodium, which are more or less necessary to the many life-forms or are employed by them in their skeletons or coverings.

Life, therefore, can affect the amounts and properties of the atmosphere.

It may be an aid or a hindrance to disintegration or erosion and deposition.

It may produce organic deposits such as peat or coal; or of organic matter like coral, shell-marls or diatom ooze.

Of these three effects, the first, though it is the least obvious, is perhaps the most important. It is thought that the carbon dioxide of the atmosphere which has fed the vegetable life-forms since their first appearance, has suffered a continuous diminution, though it has been subject to fluctuations in

amount. The oxygen of the atmosphere, though also subject to fluctuations, has probably increased in amount. Nitrogen has probably been increasing both actually and relatively, because free nitrogen is less consumed in a direct manner by life-forms. The properties of these three constituents, carbonic dioxide, oxygen, and nitrogen may be altered by the vigour or number of life-forms. One consequence has already been pointed out. Oxygen and nitrogen are more transparent to heat rays than carbon dioxide or water vapour; and therefore a considerable variation in the proportions of these gases of the Earth's atmospheric blanket would cause fluctuations in the prevalent temperature at the Earth's surface; in other words, would bring about fluctuations of climate affecting the whole globe. There is good evidence not only of extensive glaciation betokening extreme cold, but of arid periods in regions now continually moist; and of humid periods in regions which are now desert. Thus while the atmosphere admittedly must affect, and must always have affected, the forms of life: there is reason for supposing that life by its influence on the atmosphere may have been an agent in bringing about climatic changes. It need not have been the chief agent.

Such are the influences which organic life may have on the physics of the Earth. The influences of the geography of the planet in hastening or retarding organic life have been briefly indicated, and it is well to remember that the association of specific life-forms with distinctive strata, or with specified periods in the world's history, is a matter of observation and of a kind of observation which is necessarily fragmentary and incomplete. Consequently the association of a progressive advance in life-forms with the gradual accumulation of the sedimentary strata, is one which, though fundamentally justifiable, is arbitrary. It is a convenient method of linking up the inorganic growth of the planet with its developing life.

Organic and Inorganic Pedigrees

If an ideal pedigree, both of the rocks and of the development of life, were open to our observation, we should find in the earliest rocks the simplest forms of life. But while increasing observation pushes the discovery of the earlier forms of life further and further back into geological history, this ideal relation is far from being preserved, and we can only say that the character of the naked protoplasm such as must have formed the earliest living things was then, as now, of a character insusceptible of preservation.

The supposition of their existence is justifiable, because when fossils make their appearance, they are the relics of life which had already made considerable advance in organization. Again, though plant forms must have been necessary for the support of some animal forms, the plant record lags behind the animal record and is much inferior to it in number of specimens. That is partly due to the delicate nature of early types of vegetation, and to the fact that vegetation has developed most on the land—which is less capable of preserving its relics than the sea sediments, where animal forms almost from the beginning have been abundantly preserved. It was only under exceptionally favourable conditions that the oldest lands left their life record behind them.

Earlier Relics of Life

Nevertheless, all the great groups of plants, the Thallophytes, which include the algæ and the fungi and the lichens; the Bryophytes or the mosses and liverworts; the Pteridophytes or fern plants, and the Spermatophytes or seed plants, whose connexion with the ferns has been made out by the researches of D. H. Scott [1] and F. W. Oliver,[2] have

[1] "Studies in Fossil Botany," by D. H. Scott, F.R.S., 2nd ed. 1908 (A. & C. Black).

[2] A convenient summary of the investigations appeared in "Illus. Scientific News," June, 1903.

all left some record. Some of the Thallophytes are single-celled organisms and as simple in structure as a living thing can well be, and may be regarded as comparatively near relations of the ancestral forms. It is possible that some of the algæ may have been agents in forming some of the limestones which are without fossils. Of the Bacteria, which belong to the fungi, there is a theoretical probability that they flourished as far back as the records of the strata go; and they are believed to be recognizable as early as the Palæozoic rocks. The mosses and liverworts, though low forms of life, are not primitive ones; and they left no record of themselves in the earlier rocks, and no certain record even in the middle period. Of the higher groups, the ferns and their allies left abundant traces in the middle geologic period; the deposits of the plants still higher in the scale begin at the end of the middle period and are relatively modern.

It is to be noted [1] that the chief development of all the great groups of plants took place on the land, or in the land waters, rather than in the sea. This is true not merely of the higher forms, but appears also to be true of the earlier ancestral forms, the Thallophytes, though they exist in much greater quantity and numbers in the sea than on the land or in land waters. But the fresh-water Thallophytes, the algæ, appear to possess in a higher degree than the marine forms those characters from which new forms spring, and are probably the parent type. If that view be accepted it suggests that we should pause before wholly accepting the theory that life began in the sea and migrated to the land. It affords at any rate some ground for the alternative supposition that life developed primarily on the land and in the land waters and migrated to the sea.

Turning from the vegetable to the animal kingdom, there are reasons similar to those which account for the

[1] Chamberlin and Salisbury, "Earth History," p. 627.

difficulty of recognizing the Thallophytes in the earliest strata, which render the absence of the simplest animals, the Protozoa, comprehensible. The Protozoa, usually minute one-celled organisms, are in some cases so like to the Thallophytes, that the allocation of some organisms to one or the other kingdom is in doubt. Some have not been found in the fossil state at all; but others have played a very important part by their contribution to the oozes. The Porifera sponges, the Cœlenterata[1] jelly-fish and corals, are rare in the earlier rocks, though some traces of the sponges have been found in the Cambrian. Echinodermata, crinoids or sea-lilies, star-fishes and sea-urchins begin with the ancient rocks; and have left a good record behind them. The Vermes or worms, in spite of their softness, have left their tracks if not themselves in the earlier rocks. With the Brachiopoda we approach conservation. They range from the Cambrian to the present time, and some forms have hardly changed in the whole of that vast lapse of time. The Molluscs have similarly ranged from the earlier syllables of recorded time.

The Arthropoda, which embrace the trilobites, crabs and barnacles on the one side, and centipedes, spiders, scorpions, and insects on the other, are chiefly interesting not for the extent of deposits they left but for their theoretic value in dating strata and periods. The trilobite, that deservedly popular fossil, appears in the very early fossiliferous strata;

[1] "The earliest multicellular animals were possessed of one structural cavity, the *enteron*, surrounded by a double layer of cells the *ectoderm* and the *entoderm*. These *Cœlenterata* or *Enterocœla* gave rise to forms having a second great body cavity, the *cœlom*, which originated by a pouching of the *enteron* to form one or more cavities in which the reproductive cells should develop—pouchings which became ripped off from the cavity of their origin and thus formed the independent *cœlom*. The animals so provided are the *Cœlomocœla* as opposed to the *Cœlenterata*, and comprise all animals above the polyps, jelly-fish, corals, and sea-anemones.—E. Ray Lankester, "The Kingdom of Man," pp. 112, 113 (1909). See also Introduction to Part II, Treatise on Zoology. Edited by E. Ray Lankester (A. & C. Black).

it was probably the most highly developed organism of its time, and it affords the clearest evidence of the progress which life had made at the time when its record is disclosed. The land Arthropoda date from the middle period of the more ancient or Palæozoic rocks. The Vertebrates do not appear till late in the Silurian period, but they were dominant in the succeeding epochs.

CHAPTER XVI

GEOLOGICAL SUCCESSION

Classification of geological eras—Correlation of life and strata—Geographical aspects of the geological eras—The face of the Earth—The oldest continents—The Sea of Tethys—Southern continents—Land bridges—Suess's summary.

IF the growth and development of the crust of the Earth have not been gradual and uninterrupted, but have proceeded in a series of waves of irregular length; and if also the evolution of life has proceeded with an irregularity which owes its origin to unknown causes—it will be evident that the attempt to date the strata or the periods by the relics of life which they contain can only be partially successful. Therefore in speaking of the life of the Cambrian period, or the vegetation of the Carboniferous era, we are making use of convenient expressions which define theoretically some stage of progress reached by the Earth in its life history; but we are not making indisputable statements of ascertained fact. When Cuvier imagined that the Earth progressed by long periods of quiescence, chequered by great cataclysms which removed every living thing and necessitated an entirely new creation for the next epoch—it was possible to imagine geological periods which were sharply demarcated and strictly contemporaneous for the whole Earth. It was possible also to imagine species of animals and plants confined to those periods: and so to frame pictures in which one period should be characterized by widespread seas in which the fishes were given their opportunity to consolidate their family history; and another period in which the planet over vast expanses

of its surface was jungle or swamp in which vegetation flourished and evolved. But such pictures are fanciful and unreal. The geological record, as Darwin said fifty years ago, "is a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume only here and there a short chapter has been preserved; and of each page only here and there a few lines." The further discoveries of fossils in the last generation, while they have amplified the history of some species, have given rise to more problems than they have solved, and have left the origin—or rather the origins—of many if not of most life-forms in greater uncertainty than before. The obscurity may have been lightened by discovery, but speculation has been hampered.

Classification of Eras

For the convenience of the reader who is not a geologist we subjoin the classification of eras generally adopted, leaving out the very numerous subdivisions which often vary in different localities.

First Era: Archean

Second Era:	Primary or Palæozoic	Cambrian Silurian Devonian Carboniferous Permian	
Third Era:	Secondary or Mesozoic	Triassic Jurassic Cretaceous	
Fourth Era:	Tertiary or Cainozoic	Eocene Oligocene Miocene Pliocene	
Fifth Era:	Quaternary or Neozoic	Glacial Post Glacial	Pleistocene
		Present	

As we have supposed that some readers are not geologists, it may not be out of place to indicate what are the characters or criteria of these rocks by which their age is recognized, when they are, as in the case of the formations of the Alps, distorted, displaced, or overturned. The careful study of rocks enables geologists to say that certain periods impressed certain characteristics—rock characteristics—on the strata. That is what we might expect because the life of the period would naturally exercise a good deal of influence on the sediments. One kind of limestone differs from another: even as one kind of coal differs from another. But the essence of this method of recognition depends, in the final instance, on the discovery of the characteristic types of life. That is not always possible. The age of a rock has to be accepted from fossiliferous evidence in adjacent rocks. Moreover, sediments laid down at the same time in different parts of the Earth have by no means identical characteristics. It will be seen that the definition of an era by the appearance of its strata is merely an approximation.

The second method, which, being the best we have, is the one on which most trust is placed, is that of defining the period of a strata by the presence of its characteristic life—its "characteristic species". If we consider broadly a number of strata which are neighbours to one another in time as well as in place, we find them characterized by some family or group of species. For example, the Trilobites are the most characteristic types of the Primary strata; the Ammonites characterize the Secondary strata; the Nummulites characterize the Tertiary period. But the Trilobites do not last through the Primary period. They disappear before the end of it. The Ammonites, though characteristic of the Secondary Period, are found in the Permian. "It was in this, as in not a few other cases, a Permian function to welcome the coming and speed the

parting guest."[1] The Nummulites of the Tertiary period begin to disappear from the Eocene strata: but it now seems certain that they appear before the Tertiary period began in the later cretaceous strata of the Secondary. There are instances where an enormous development of some life-forms gives a distinctive aspect to a group of strata. The carboniferous is one example. The tremendous burst of reptilian activity in the Secondary is another. But the most typical of these stratas pass insensibly into their neighbours and their extent is geographically limited. For example, the great reptiles with few exceptions have been found in large numbers only in Central Europe and North-Western America.

Correlation of Life and Strata

In the second place there are a number of families and systematic groups of life-forms which are distributed through only a part of one of the greater formations, and which are thus associated with a limited number of strata. The end of one group rarely coincides with the beginning of another; it is still rarer to find different groups beginning and ending together at the same level; the limits of the typical forms are mingled in the most complicated fashion. If a coincidence such as we have imagined is ever discovered, further research always extends the period of the fossil in one way or another. Even if such coincidences could be established what value would they have? Could we lay down great divisions in the complex life of the planet on the strength of a coincidence which might be accidental and which involved only a limited number of organisms dwelling in a restricted area?

The geographical considerations affecting the face of the Earth are, as we have repeatedly pointed out, those which

[1] Chamberlin and Salisbury, "Geology," Vol. II, p. 655.

are brought about by the advance and retreat of the oceans. By hypothesis, the changing relations between land and sea have been brought about with extreme slowness. The study of fossil remains determines the length and the nature of those transgressions and regressions of the waters. If above the beds containing marine forms we find others with fresh-water forms or terrestrial forms we deduce that the sea was retiring—and vice versa. If two contiguous series of beds exhibit opposite characteristics then they must have been laid down under different conditions. In one case the sea was advancing: in the other retiring. This kind of investigation no doubt furnishes useful results, but it has its limits of usefulness. If each advance of the sea had extended to all parts of the planet, this method of classification would have been of the highest value. But as a matter of fact that is by no means certain. For example, there was a great advance of the oceans between the Palæozoic and the Mesozoic strata in North America, in Russia, and in England. But this advance is not found, or at any rate it has left no trace, in the Alps, in India, or in Africa, where the passage from the Palæozoic to the Mesozoic goes on without a break.[1] Again, between the Mesozoic and the Cainozoic there is a break in the Mediterranean basin, and the Lower Eocene is missing. Elsewhere there is no break. Instances might be multiplied. They point to the same conclusion: that the shore lines of the world are continually being shifted and in some cases so slowly as to require the whole of a "period" to demonstrate any effect. But it is doubtful whether these transgressions follow one another in such a way as to delimit periods. In brief, the further knowledge is pushed the less regular do any alterations in the face of the globe or in its life appear to be, and the more artificial become the

[1] "La successione degli strati," P. Enriques and Mr. Gortani in "Revista di Scienza," 1909, pp. 277-91.

boundaries which classification has fixed. The modifications of the face of the Earth and of its life have been gradual and continuous since the geological record declared itself.

Stress has been laid both in this chapter and in the preceding one on these considerations, because while attempts to furnish pictures and even maps of the state of the planet in past geological eras, have a fascination for geologists as well as for those whom they instruct, it must be clearly understood that these visions are often of doubtful authenticity; and that there are few general statements of this kind which have worn well. The "probable landscapes" of the Cambrian period, with seas encroaching over barren lands, may be true for restricted localities in that irrecoverable epoch; but it is equally likely that the conditions of life, of climate, and of the relative proportions of land and sea were entirely different in some of those parts of the globe, the geological history and fossil record of which have not been sufficiently examined. How far geologists have receded from these early speculations as to universality of conditions is best seen, however, in respect of the opinions now held concerning the Carboniferous epoch. It was roundly assumed that in that epoch the globe remained swaddled in a dense vaporous atmosphere; with half light, great warmth, and a sub-tropical vegetation which under these conditions flourished from Pole to Equator. But we now know that long before this period, in the Cambrian era, India was probably a desert; and that in the later era of the Silurian, what is now the well-watered region of the great lakes of North America was as desert as Arizona is to-day. Coal, which it used to be supposed was laid down only with a luxurious sub-tropical vegetation and conditions, is now in progress of being formed in Alaska and Labrador; and many of the Carboniferous plants show by their structure an adaptation to severe rather than tropical conditions.

Geographical Aspects of the Eras

The only pictures that can be profitably drawn are, therefore, companion pictures, of which the relativity is rather dubious, one of which shows the land rising or sinking, or stationary in the fifteen periods into which geologists divide the duration of the stratified rocks ; and the other of which shows, in an even more fragmentary, tentative, and local way, the rise and growth and decay of some of the forms of life. In this kinematographic succession of pictures the earlier ones would be the most blurred, and the least trustworthy. Of the earliest period, the relics of which are called the Archean rocks, the only speculation which has any substance is that the period in time which they represent is probably longer than that of any of the others. The greatest depth to which exploration of the rocks has been carried reveals even when upturning and erosion of the strata are taken into account, only a few miles [1] of deposition and aggregation. The lowest rocks which exploration reaches consist of a very complex series of formations, embracing lava outflows, volcanic products, and tongues and bosses of igneous rocks which have been thrust up from a lower level, together with some rocks which, though they have been distorted, crushed, and fired, nevertheless bear traces of having been laid down as sediments. Fossils are not found, but the nature of the rocks, the carbon shales, the limestones and schists and iron ore found in them justify the belief that life existed when they were formed ; and that belief has other warrant on the ground that when fossils do appear they reveal a development and organization

[1] The deepest boring is that made by the Austrian Government in Silesia, and is a mile and a quarter in depth. The deepest shafts sunk for industrial purposes are the Bryer shaft at Ronchamp in the Haute Saone, which is 1010 metres, and a 5,000 feet shaft near Lake Superior. The Hon. Charles Parsons has made the interesting calculation that a twelve mile shaft would take eighty-five years to construct and would cost £5,000,000.

which implies that a great interval of time must have elapsed since they were begotten from lower forms. Under the planetismal hypothesis which has been that adopted for the main part throughout this volume, the oldest known rocks may be confidently referred to this era, for according to this hypothesis, rocks of organic origin (like the carbon shales or limestones) were not only mingled with all the rocks that we can see, but with a deep series far below—since life is supposed to have originated before the Earth ceased to grow. These rocks, belonging to the Archeozoic, or first life era, are commonly called Archean. Originally the term was made to include all rocks below the fossil-bearing Cambrian, but it is now known that there are three or more great systems of sedimentary rocks, or of rocks which are sedimentary and are interbedded with igneous sheets, below the Cambrian ; and that these systems do not lie evenly one on the other. Since these systems are very thick and are separated from one another by conspicuous but unascertainable intervals, they represent a vast lapse of time, probably quite comparable to that of the Palæozoic, or Mesozoic, or Cainozoic eras ; perhaps as great as all three together.

The Archean is the one accessible system which is theoretically universal in the sense that it underlies the whole surface of the globe. Wherever it comes to the surface all later systems are undiscoverable. Ignoring all accidental superficial coverings we may say that the Archean rocks are estimated to appear over about one-fifth the area of the land, but since much of Asia, Africa, South America has only been partially scanned, this estimate is only a general one. Canada has the greatest area of Archean rock at the surface, taking in Labrador, thence south westward to the Great Lakes, and onwards north-westwards to the Arctic Ocean. In Great Britain the Lewisian gneiss of the Outer Hebrides is regarded as Archean ; there are outcrops of Archean in

Norway, Sweden, Finland, France, Bavaria, and Spain; as also in India, northern China, Japan, Australia, Tasmania and New Zealand. Between the Cambrian and these rocks, which till the year 1830 were believed to be the oldest of formations and quite insusceptible of classification, are the series known under various denominations, but broadly classified by American geologists as the rocks of the Proterozoic era,[1] when life certainly existed. These rocks have received the most careful examination in North America, where they crop out in many places formerly delineated as areas of Archean rock. In Great Britain they possibly can be identified with outcrops in Charnwood Forest, Anglesea, and the Malvern Hills. Sir Archibald Geikie identifies the Torridonian sandstones, nearly 10,000 feet thick, in Scotland, with the Proterozoic era; and in France, Spain, Finland, Scandinavia, India and Brazil, rocks which are older than the Cambrian, and yet are not the oldest rocks of all, have been found.

The foregoing tentative description of the extent of the earlier rocks and the areas they may have been presumed to occupy, conduces to a proper attitude of reserve in delimiting the continents and oceans when the later formations were deposited. The most comprehensive authority whom one can follow in these speculations is Suess.[2] Suess, as we have noted in the preceding chapter, is not convinced as to the permanence of the ocean basins, and regards the present distribution of land as dating from no earlier than the middle period, or Mesozoic era. The difficulties which confront the inquirer are chiefly those of what we call the Old World—a term possessing a significance of its own in geological history.

[1] In England "Proterozoic" in a term used for the Lower Palæozoic—Deuterozoic for the Upper Palæozoic.

[2] "The Face of the Earth," op. cit.

SUESS'S "FACE OF THE EARTH"

Neglecting for a moment the Palæozoic era beginning with the Cambrian and ending with the Permian, and considering the Mesozoic period which ended with the Chalk, we find, according to Suess, that North America was covered by the sea, during the Cretaceous or chalk period, from the Gulf of Mexico to the Mackenzie River, and perhaps as far as the Arctic Ocean. All the region which lies between its Western mountains, and the mountains which rise in the East, lay under water; and some of the mountain ranges were themselves submerged. The ocean basin then filled, or the ocean bed rose; the sea disappeared, leaving behind it an extremely large inland sea of brackish or partly fresh water. This was the prehistoric Lake Laramie, which stretched over the interior of the existing continent from latitude 33° to latitude 60°. Lake Laramie has disappeared, but North America dates from its existence; it is perhaps the newest continent; it is certainly the simplest. South America has been too little explored to unfold a history of equal candour. But fresh-water deposits of a period later than the Cretaceous have been found 1200 miles from the Atlantic coast; and Tertiary fossils of a similar kind advance far inland from the south-east; so that South America, too, may be regarded as a Newer Continent.

THE OLDEST CONTINENTS

But, says Suess, if we attempt to make similar inquiries with regard to the united mass of Asia, Africa, and Europe, we find that they are far from being similar regions. They are heterogeneous masses which have been welded together and the limits of which are not like recognised continents. The most ancient of these masses would consist of South Africa and a large part of Central Africa, together with Madagascar and the Indian Peninsula. These lofty table-

lands have never been covered since Palæozoic times, or the end of the Carboniferous period; and to them collectively, has been given the name of Gondwana land, the oldest continent, incomparably older than North America.

Gondwana land is followed on the north by other plateaux, which were submerged during the Mesozoic era, in the Cretaceous period, and remained partially submerged into the next era, the Cainozoic or Tertiary. To this era, the birth of which is near in time to that of the North American Continent, belong the Sahara, Egypt, Syria, and Arabia. Added to ancient Gondwana land, they form Indo-Africa. It is a region which has undergone no mountain folding since the close of the Palæozoic era.[1]

Subtracting "Indo-Africa" from the rest of the great land mass of the eastern hemisphere, that which remains is Eurasia—Europe plus Asia. The whole of the southern border of Eurasia advances in a series of great folds towards Indo-Africa. The whole southern part of Eurasia is a folded region stretching from the series of Himalayas. These great assembled folds, always pushed towards the south, cover a breadth of twenty-two degrees of latitude. They run south in a series of syntactic arcs; further north they are extended by rod-like branches. As they travel westwards, and reach Europe the branch stretching past the Cacausus undergoes a reversal in the direction of the folding, and passing through a mighty twist in Roumania is driven, in the Carpathians, and in the main part of the Alps, towards the north. A great part of this folding is of recent geological age; it is continued into recent times; and the movement may not yet have ceased. It is extremely likely that within the

[1] We have already cited Suess in support of the belief that mountain building does not arise by elevation from below, but by processes of lateral pushing. "The dependence of the processes of mountain formation on older elements which check and oppose—on lateral pressure and deflexion—becomes daily more evident." The North-West of Scotland, for example, is thrust over the gneiss of the Hebrides.

region occupied by the existing folded ranges, an uninterrupted sheet of water stretched at one time from Turkestan to China, where Han Hai, the Chinese "dry sea," marks its eastern limit.

THE SEA OF TETHYS

North of ancient Gondwana is a broad zone of deposits left by the seas of Mesozoic times. From Tunis to Sumatra they are found; they embrace Tonquin and Asia Minor, the mountain regions of the Hindu Kush, the Pamirs, the Himalayas and the Trans-Himalayas disclosed by Dr. Sven Hedin. They are the relics of that ancient sea sometimes called Tethys, and described by Neumayer as the ancient Central Mediterranean. The present Mediterranean is a relic of old Tethys.

Further north again, built on a foundation of Palæozoic rocks, is the East Siberian platform. From China to the Antarctic are laid beds of the Cambrian times, and above them beds of the Silurian, all very evenly laid. They have suffered little disturbance. Above these again come layers of plant-bearing beds, perhaps of the Permian period, some of them leading on to the second division of rocks, the Mesozoic, and belonging to Jurassic times. These plant-bearing beds of China, Mongolia, and Siberia, bear witness to the birth of a second great continent north of old Tethys. This continent, younger than Gondwana, and younger than the continent of which relics appear in Canada and Greenland, is yet very ancient. To it has been given the name of Angaraland. In its strata, the Angara series, are included all the known plants of the last of the Palæozoic periods, the Permian, as well as those of the Mesozoic era. Towards the close of the Middle era the sea of Tethys disappeared; and a good deal of the Siberian Tableland was never again covered by the sea. With the disappearance of Tethys and the union of the ancient continent of Angara to the lands farther south arose the existing continent of Asia.

One other continent remains to be considered, besides that ancient Laurentia which has taken its name from the Archean rocks found in the neighbourhood of the St. Lawrence. It is the lost continent of Atlantis. As we have observed, Suess does not accept unconditionally the theory that the ocean basins have remained unaltered and remain unalterable. He regards the elevation of their basins to a height at which they become land platforms as possible if not probable. Suess sees no reason why parts of the ocean or even of the dry land may not to-morrow sink to form new depths, *or why we should believe that all the grèat ocean basins have been continuously covered with water since first they were formed. So far as the Atlantic is concerned there even exists some evidence to the contrary*. The evidence which Suess indicates is the nature and distribution of the sediments laid down in Palæozoic times in Europe and Africa; and his hypothesis is that the position occupied by the North Atlantic was occupied by a continent to which is given the fabled name of Atlantis. Greenland is a remnant of it.

Southern Continents

Of the southern continents, the Falkland Islands, off South America, afford us some glimpse of an ancient history, because these islands are a folded fragment of Palæozoic schists; and the thrust of the most ancient strata accessible in South America affords room for speculation concerning a continent which filled the ocean between Africa and the existing western continents. It is permissible to imagine ancient Gondwana joined to ancient South America (arch-Amazonia) by way of South Atlantis; and a huge land platform thus extending from Sinai to the great area of Brazil and Argentina, while Antarctica was joined to Australia and Patagonia.

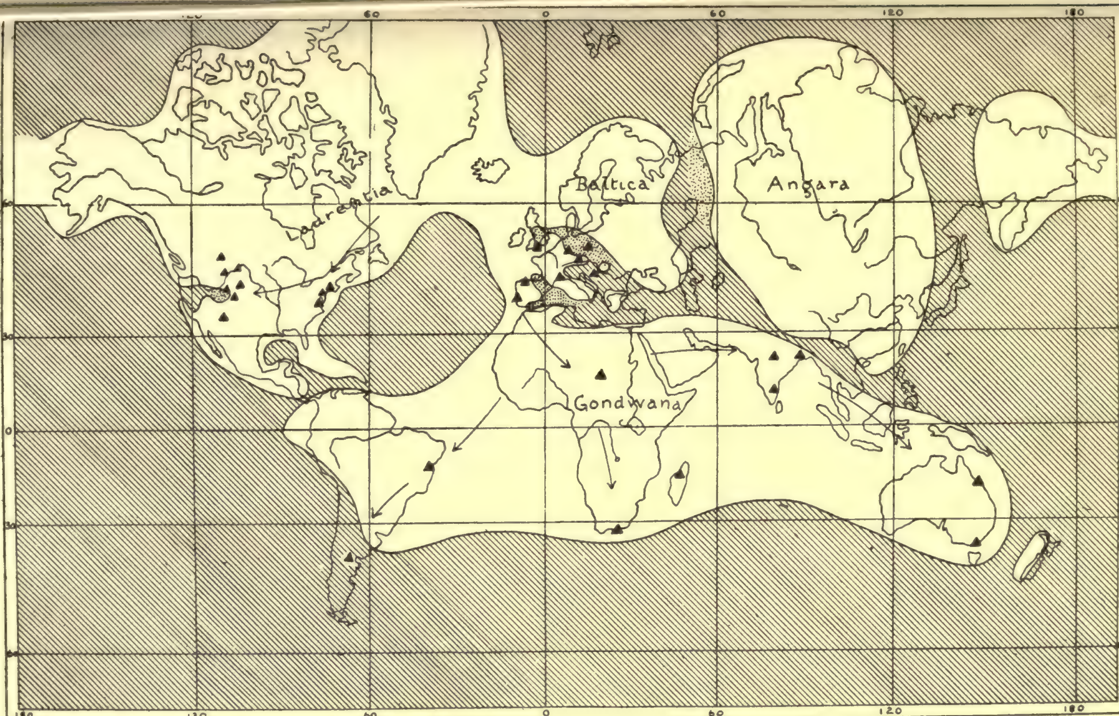


FIG. 23.—Distribution of land and water in the Secondary Period based on the lower Triassic maps of Schuchert for North America and De Lapparent for the rest of the world. From an article by Dr. R. S. Lull of Yale University on Dinosaurian Distribution ("American Journal of Science," Vol. XXIX, No. 169).

Land Bridges

To the north of Iceland, there are indications that a land bridge may have existed between the lands of the two hemispheres, though it was probably frequently interrupted by transgressions of the sea. (Dr. R. F. Scharff[1] is of opinion that there was a land bridge between North Europe and North America as late as Pleistocene times: and that the connexion was by way of Greenland and Iceland.) Further, to sum up some of the known aspects of the Earth during the earlier geological eras: Iceland, like the Faeroes, shows remnants of an ancient volcanic era, and has a newer volcanic substratum built on the older one. Iceland has in fact been continuously and actively volcanic from the middle Tertiary times to the present day. The Canaries also disclose older volcanic remains beneath newer ones. Spitzbergen is a relic of the Palæozoic plateau, with Devonian lake beds above it, and the Orkneys and Shetlands are part of a mountain range which arose on a Silurian epoch; and are part of the same ancient Caledonian range which strikes over towards Norway.

Following on the period of shallow lakes which characterized the Devonian era in Europe, came that so-called Carboniferous era of which the most pronounced feature is the development of plant life and the deposition of its remains. Towards the close great mountain ranges arose in Central Europe, and these ranges were folded towards the north like the existing Alps. They then collapsed and their fractured borders resisted the development of the new folds. (If a number of thicknesses of felt be pushed up against a solid obstacle, or even if one considers the familiar operation of accidentally rucking up a rug with the leg of a table or a chair—the opposition of a block of ancient mountains, sometimes called by geologists a "horst," to the

[1] "Proc. Royal Irish Acad." 1910.

sideways pressure of newer strata can be pictured.) The new folds thus contorted now form the Pyrennees, the Alps, the Carpathians. The fragment of the older range which still exhibits the ancient development, now separates the Alps from the Pyrennees. Thus far we have relied on Suess, and have endeavoured to interpret the main drift of his theories. With regard to subsequent developments, it seems desirable to quote him more precisely.

Suess's Summary

"If we now consider the succession of beds in those parts of the continents which have been so far closely investigated we discover that vast areas have been subject during periods of extraordinary duration to marine overflows or transgressions, that is, to positive movements interrupted by negative phases. .

"At the close of the Silurian epoch the strand receded across the whole region lying between Illinois and the Atlantic Ocean, as well as in England, the north of Russia, and near the Baltic. The Old Red Sandstone, like a lake, overspread the whole North Atlantic region, the east of Canada, Spitzbergen, Scotland, England, the north of Russia.

"Then the sea began its advance, and by the middle Devonian the sea's transgression was felt over Russia as far as Livonia; perhaps over Western Canada and the Arctic.

"It receded at the beginning of the Carboniferous; it advanced again, other oscillations followed till the marine sediments of the Permian covered part of North America and North Europe and brought the Palæozoic movements to an end.

"The Mesozoic seas of Europe, though sometimes they receded, never failed to regain ascendancy. A very large part of Europe was thus submerged, Scotland being nearly under water. The Mesozoic seas even reached Abyssinia. The submergence continued. It began to dwindle, and the

sea was for a period left only in possession of places like the Alps from which it had advanced.

"At this stage the Cretaceous epoch begun and the sea advanced till it overwhelmed the ancient Jura ranges, and the whole of Central Europe with its great fresh-water lakes was again covered by the sea. Russia had in the previous retreat become dry land, but now the sea advancing from the south joined hands with the sea by the north. The southern sea swallowed its weaker partner.

"Then for the first time the Atlantic coasts as they exist now were washed by the Ocean. The sea covered the plain of Patagonia, and perhaps extended over the whole continent of South America: from Texas it made its way through the middle of North America to Lat 65°N. It left its traces around the greater part of Africa, covered a great part of Europe, reached the Caspians, the sea of Aral, Persia, Syria, the Eastern Sahara, Arabia, the coasts of India. Greenland, North Russia, Spitsbergen, North China, North Siberia alone were unaffected by this great sea advance of the Cretaceous age. Once more vast areas were abandoned by the sea. Everywhere it receded: the Cretaceous period came to an end and the Tertiary epoch begins. The retreat was more complete even than the advance, for the new fresh water lakes lay closer to the Mediterranean whence the overflow had sprung than ever before. . . . Henceforward the conditions become so complicated that it is no longer possible to give a general and concise account of them."

II

With regard to Suess's belief that the oceans and the land are similarly liable to depression and to elevation we may quote Mr. Mellard Reade's [1] calculations of the amount of sediment passed into the Atlantic. It amounts to 1200 million tons annually. He also points to movements both

[1] "Earth Structure" by T. Mellard Reade (Longmans), 1905.

of elevation and depression in existence now on continents and remarks that there seems no reason, from a mechanical or dynamical standpoint, why oscillations by level should be restricted to 9,000 or 10,000 feet. The only difficult thing to account for are the so-called ocean deeps. In Mr. Reade's view they are produced by a sagging of the Earth's crust similar to that which produced the Mediterranean basin. They are not necessarily permanent.

The classification embodying the conclusions reached by Prof. Suess after thirty years of most careful research, must command respectful attention from all geographers though objection may be taken to some parts of it.[1]

[1] In an Appendix to his last published volume of "Das Antlitz der Erde." Vol. III, pt. ii. (1910), pp. 783-705. Suess gives his final summary of the lands of the Earth. He arranges them in the following ten divisions :—

1. Eurasia, including part of North America.

2. Laurentia.

3. Gondwana land.

4. Australia Oceania, and parts of Antarctica.

5. South America and the western mountains of North America.

6. The British Islands, excluding the southern counties, but including part of Norway, and the mountains of the Western Sahara.

6. The volcanic islands of the Atlantic type, with which are grouped some of the islands of the Eastern Pacific, Indian and Southern Oceans.

8. The Cape Mountains.

9. The north western peninsula of New Guinea.

10. The Fiji Archipelago.

J. W. Gregory, "Nature," 16 June, 1910, p. 452.

CHAPTER XVII.

ORGANIC DEVELOPMENT.

Development of species—Succession of plants—Gaps in the record—Genetic connexions—The flowering plants.

WHILE it is possible to say that given forms of life were present in great numbers or exhibited many evidences of development in given epochs of the planet's geological history, it is no longer possible to say that this or that species was born in a certain era, and it is hardly possible to say that any species was chiefly characteristic of an era. The most that can be said is that this or that fossil makes its first known appearance at some defined stage; that it seems to develop chiefly in some epoch less well defined; and that after some point it appears to be succeeded by some other form, sometimes related, sometimes divergent.

The trilobites for example appear in the Cambrian and seem to attain their maximum development in the period called the Ordovician between the Cambrian and the Silurian. On those stretches of land which were bared during the Silurian epoch insects have left their first record;[1] and the Silurian seas were peopled by the earliest fish we know. In the Devonian the fish are found in increasing numbers and

[1] "That true insects existed has been made known by the discovery of an orthopterous wing (*Palæoblattina*) in the lower Silurian sandstone of Jacques Calvadas ("Geol., Mag.," 1855, p. 481). It measures about $1\frac{1}{8}$ inches long. . . . A hemipterous wing has since been obtained from the lower Graptolite shales of Sweden" (Geikie, "Text Book of Geology," Vol. II, p. 943).

the fresh-water fish have stamped their impress on the rocks. In the Carboniferous the fossil mosses[1] which had been reinforced during the Devonian by true ferns, have developed into a fossil flora the abundance of which has dwarfed all other records of this epoch. In the last of the Palæozoic periods, the Permian, the reptiles declare themselves; but the reptiles, judged by the abundance of their remains, belong properly to the Mesozoic or Middle Era, i.e., to the Triassic and Jurassic and Cretaceous age. The birds began long before the Central Mediterranean submerged the larger part of Southern Eurasia; the oldest known fossil bird, the *Archæopteryx* dates from Jurassic times.

In the Cretaceous period the sea birds must have developed; and their fossils, many of swimming birds, others of birds with considerable power and spread of wing, testify to the expanse of sea and to the double impulse which it gave to two lines of development among the birds. To the Triassic strata belong the earliest traces of mammals;[2] but they

[1] "The land of the Silurian period probably had a cryptogamic vegetation in which lycopods and ferns played the principal part" (Sir Arch. Geikie, "Text Book of Geology" 4th edn., Vol. II, p. 937). Geikie qualifies this observations, however, in a note, by saying that Zeiller in his recent Text Book remarks that the evidence of any plants in the Silurian period of higher grade than algæ is exceedingly meagre. D. H. Scott ("Studies in Fossil Botany," 2nd edn., p. 6) says that though most of the Silurian remains are very doubtful there is some evidence that even at this early period vascular plants had already appeared.

[2] "One of the most noteworthy facts in the palæontology of the Trias is the occurrence in this system of the first relics of mammalian life, in what are believed to be detached teeth and lower jaw bones. These have been referred to small Prototheria, which present some resemblance to the Banded Ant Eater of New South Wales (*Myrmecobius*). The European genus is Microlestes. In the Trias of North Carolina a supposed marsupial has been described under the name of *Dromatherium*. It is possible, however, that some of these remains may be reptilian" (Sir A. Geikie, "Text Book of Geology," 4th edn., p. 1091). These were the highest types reached before the beginnings of the Cainozoic period (op. cit., p. 1083). Then—in the Lower Eocene—appeared the primitive carnivores *Arctocyon* and *Palæoncitis*: Middle Eocene was distinguish by tapir-like animals: the Upper Eocene

developed slowly and it is the epoch which succeeds the secondary rocks—the Cainozoic or Tertiary—which has been called the Age of Mammals. Possibly the foregoing rude outline of development may be the only one blameless of the vice of over classification.

Development of Species

In an ideal completeness of knowledge with regard to the life forms of the past the hope might be indulged that we should be able to trace the growth and descent of every form of life; that with the earliest strata we should see the beginnings, and that with each succeeding stratum we should see the additions and alterations as the types grew more and more complex—the establishment of a new type on the ruins of an old, its progress, and its decay. "How glorious it would be if we could arrange the organized products of the universe in their chronological order," said Cuvier. "The chronological succession of organized forms, the exact determination of those types which appeared first, the simultaneous origin of certain species and their gradual decay would perhaps teach us as much about the mysteries of organization as we can possibly learn through experiments with living organisms." It was an aspiration which has now ceased to be an expectation. "If the evidence were complete and available we should hardly be able to unravel its infinite complexity, or to find a clue through the mazes of the labyrinth," observes Prof. W. B. Scott[1] and similar observations are made by Dr. Dukinfield Scott[2] and Dr. A. S. Woodward.[3] "There may be several vegetable kingdoms," says the palæobotanist. "Many animals of the

added animals midway between the tapir-like animals and the true horse-like animals. There appear to have been also representatives of our hedgehogs, squirrels and bats (op. cit., 1227).

[1] "Darwin and Modern Science," Camb. Univ. Press. [2] *Ibid.*

[3] British Assoc., Pres. Address to Geological Section (1909).

same general shape and habit have originated two or three times at two or three successive periods, from two or three continually higher grades of life," says Dr. Woodward. A species develops like an idea. Faraday discovered the possibility of rotating a magnet by electricity: but imagine the difficulty of tracing step by step and inventor by inventor the pedigree by which the electro-motors of the London Tube railways have descended from that ancestry in fifty years. How immensely more difficult would be the task of tracing through all its vicissitudes of generation and environment the progress of a species through a million years.

One of the typical difficulties arises with the first life forms. The first-known fossils are those of a crustacean [1] and they are found in rocks before the Cambrian; the Cambrian trilobites were the most characteristic and the most eminent of the inhabitants of the Cambrian seas. The significance of the fact that the oldest definite fossils include well-developed crustacea, forms which are comparatively high in the animal kingdom, can escape no one. Life must accordingly have been in existence for a long time. An immense proportion of the whole history of life lies behind the lowest fossiliferous rocks; and as Dr. Dukinfield Scott points out, the case is worse for plants than for animals, because the record of the plants begins much later than that of animals, though it is generally assumed that the lowest plant forms preceded the lowest animal forms. But as we have already said, we know nothing of the origin of life: and it is as probable that life began on this planet with many things as with one. If the first living things were many they may not have been similar; at any rate

[1] "The best preserved fossils are those of eurypterus-like crustacea. There are also tracks of two genera of annelids and other undetermined forms. Besides these certain fossils there are obscure forms which appear to be referable to brachiopods and pteropods" (Chamberlain and Salisbury, "Geology," Vol. II, pp. 216, 217).

they may have been exposed to different conditions from their origin. In either case there would have been a number of distinct series from the beginning and if so we should not be justified in assuming that all organisms are related to one another.

One more remark concerning the trilobites, before following out the general plan of this chapter, which is to indicate some aspects of relationship in the descent, first of the plant, and then of the animal kingdom. Some deductions as to the light of the globe were made from the eyes of the Cambrian trilobites. Many fossil trilobites reveal eye organs which are atrophied; others had eyes which were extraordinarily developed. Prof. Lowell assumes that this was due not to the fact that they lived in deep seas, and either did not want eyes, or else required eyes that captured every dim ray of light—but to the fact that there was little light to absorb.[1] He rejects Suess's modest supposition that some were deep-sea creatures: and argues that they lived in shallow seas. Recent inquiry shows that at a depth of as little as 400 metres there is practically no penetration of light from above. At an average depth of about 200 metres profound darkness reigns.[2] But that is not the point at issue. The mere fact that the Cambrian trilobites exhibited differing development of the eye organs shows that for ages there must have been light in order to call eyes into existence at all. The eye must have been developed before it became atrophied.

Succession of Plants

The question of the succession of plants is in a different position at the present time from that of succession in the animal kingdom. So bewildering is the material (no less than the gaps in the material) which the study of fossils

[1] "Evolution of Worlds," op. cit., 178, 179.

[2] "Life in the Sea," Johnstone, Camb. Univ. Press.

has placed at the disposal of the zoologists, that despite the usefulness of Darwin's theory of evolution, there are many who would call in other causes to explain the origin and descent of species. The same tendency exists among some botanists; and as already noted De Vries has many followers in his theory of "Mutation" as distinguished from Darwin's indefinite variation. Two of the most distinguished French palæobotanists, Grand Eury[1] and Zeiller[2] are of opinion that the facts of fossil botany are in agreement with the "sudden appearance of new forms". These new forms would differ in a very marked way from those from which they had sprung; and a new birth of this kind is held to be necessary to explain some of the sudden transitions in type of foliage which occurred in the Mesozoic era. But Scott points out that the kind of large Mutation which Zeiller or Arber[3] want is quite different from the small changes which De Vries believes he has shown to be possible to-day. Scott also remarks that though there are still many gaps in the succession of plants, yet that fossil botany has tended to fill them up, and that though the greatest respect must be paid to the opinions of Grand Eury[1] and Zeiller on the succession of species, yet the explanations which Darwin gave of apparently sudden changes from one form to another still go a long way to account for the facts which recent writers have been tempted to ascribe to saltatory variation — in other words to spontaneous jumps.

Scott[4] describes the fossil record of plants as one that

[1] C. Grand Eury, "Sur les mutations de quelques Plantes fossiles," "Comptes Rendus," CXLII, p. 25, 1906.

[2] R. Zeiller, "Les Vegetaux Fossiles et leurs Enchainements," "Revue de Mois," III, Feb. 1907.

[3] Arber and Parkin, "Origin of Angiosperms," Journ. Linn. Soc. Botany, Vol. XXXVIII, p. 29, 1907.

[4] For the theories in this chapter reference may be made chiefly to Dr. D. H. Scott's "Fossil Botany," and his article on "The Palæontological Record," in "Darwin and Modern Science".

is the story of the successive ascendancy of a series of dominant families each of which rose to its greatest height in organisation as well as in the extent of its dominion, and then sank into comparative obscurity, giving place to other families which under new conditions were better able to take a leading place. As each family ran its downward course, either its members underwent an actual reduction in structure as they became relegated to another way of life (like people who, coming down in the world, have to give up their town house and live in a country cottage or *en pension* at Dinard); or else the higher branches of the family were crowded out altogether while only the poor relations were able to keep alive by refraining from competition with the ascendant races of the *nouveaux riches*. In either case there would result a general lowering of the standing and organization of the group. This is one reason why the past history of plants by no means shows a regular progression from the simple to the complex. The other reason is that real progress is often from the complex to the simple. One of the best examples is in the case of the seeds of plants. The seeds of the Palæozoic era were nearly always very complex structures, far more complex than any to-day, except in a case of a few gymnosperms which retain their ancient characters. Reduction is not even generally the same thing as degeneration; and simplification of parts has been one of the most usual means of advance for the organism as a whole.

In tracing the pedigrees of plants, fossil botany has been compelled to confine itself chiefly to progression in the way of joining up great classes of plants rather than in tracing the descent of particular species or genera of recent flora. In this respect it differs from the animal record which has lately been successful in tracing the descent of several living species. The reason for the difference is that the later botanical record since Tertiary times is extremely

unsatisfactory: and consists chiefly of impressions of leaves, "the conclusions to be drawn from which are highly precarious". The relics of the earlier rocks are at present less chary of trustworthy information.

In the Cambrian rocks there are some ill-defined stem-like or frond-like impressions which may be, in part at least, the casts of seaweeds. There is a peculiar form consisting of little clusters of radiating rays—rather like Japanese fans in appearance—found in the Cambrian rocks of Ireland, and this is sometimes thought to be the relic of algæ. But it is uncertain; though theoretically there must have been abundance of plant life in the Cambrian seas. The record of marine plant life, no less than that of land plants, continues unsatisfactory through the succeeding ages of the Ordovician and the Silurian. In the Devonian the evidences of the algæ go on as before; and there are sections of what is interpreted to be the stem of a gigantic seaweed sometimes reaching three feet in diameter.[1]

The land plants have no more satisfactory a record in the earlier rocks than the marine plants. In the Devonian a number appear very well developed. In the Carboniferous the evidence of plant life is overwhelming. The difference between the forms of the plants in these eras makes it necessary to suppose either that the plants had an ages-long history behind them, in which they might have differentiated and developed; or else that there was a very rapid evolution; and a very rapid extension of intermediate forms.

In the placid Devonian basins, ferns and their allies and the Lower Gymnosperms were abundant. There is no evidence of liverworts or mosses, nor of terrestrial algæ or fungi; though bacteria have been found—a very interesting fact when the smallness and fragility of bacteria is taken

[1] Nematophycus. It may have been the climax in size of this form of seaweed.

into account. The ferns and a form between ferns and cycads were present; and so were the other two sub-classes in the group (Pteridophyta) to which the ferns belong—calamites, gigantic ancestors of the horsetails and club mosses (lepidodendrons). Conifers and representatives of the ginkgo tree have been reported, but have also been denied; though there is no longer any doubt that the class above the Pteridophytes in development was reached, and that in the gymnosperms the seed-bearing plants were represented.[1]

Genetic Connexions

In the Carboniferous era, the budding promise of the Devonian reached its climax. The plants have been extraordinarily preserved, and this may have given to the era a degree of prominence in plant life when compared with

[1] The accompanying classification may be of assistance to non-botanical readers. It represents provisionally the main divisions of the vegetable kingdom.

Lower Plants

1st Group. THALLOPHYTA:
- Class 1. Algæ.
- Class 2. Fungi.

2nd Group. MUSCIENÆ:
- Class 3. Hepaticæ (Liverworts).
- Class 4. Musci (Mosses).

Higher Plants

3rd Group. PTERIDOPHYTA:
- Class 5. Filicineæ (Ferns).
- Class 6. Equisaetaceæ (Horsetails).
- Class 7. Lycopodinæ (Club-mosses).

4th Group. PHANEROGAMS: True seeds.
- A. GYMNOSPERMS (Cycads, Conifers).
- B. ANGIOSPERMS. (Flowering Plants).
  - Class 9. Monocotyledons
  - Class 10. Dicotyledons

the eras on either side of it that it did not really possess. But it was truly a great period in plant life. Never before or since have the Pteridophytes (ferns, horsetails, club-mosses) been so widely spread. It was emphatically their period; and their numbers, size, and organization were unsurpassed. There were true ferns, transitional ferns, fern-like conifers; horsetails and gigantic lycopods,—all the great divisions of the group, and all nearly or quite at their climax, or verging into other groups.

The ferns, it may be said in general terms, go back to the earliest known period, though Scott remarks that in the Palæozoic era the class were less extensive than formerly believed, because a majority of the supposed ferns of that age have proved to be seed-bearing plants. The most interesting discovery of recent years has been the identification of the link between the ferns and the seed-bearing plants. Plants which combined the characteristics of the ferns and the cycads, were found in the Carboniferous by Williamson,[1] and in 1897 they were called Cycadofilices. In 1903 Oliver and Scott identified a fossil seed[2] as belonging to one of this class of plants; and since then other discoveries have come to light which make the connexion and the descent clear and unmistakable. The general conclusion which follows is that in Palæozoic times there was a great body of plants which had attained the rank of seed-bearing plants (Spermatophyta); and from them the abundant cycads of the succeeding Mesozoic era sprang. That fact is of far-reaching significance, for according to Scott there is reason for believing that the Angiosperms or flowering plants themselves sprang in later times from the cycad stock. Thus in a broad sense the main line of descent of the Phanerogams was through the

[1] Phil. Trans. Roy Soc. 1887 B. p. 299.

[2] The seed *Lagenostoma*, the tree *Lyginodendron*. References: F. W. Oliver and D. H. Scott, "On the structure of the Palæozoic Seed, Lagenostoma Lomaxi," "Phil. Trans. Roy. Soc.," Vol. 197, 1904.

fern stock. The affinity between the oldest seed plants and the ferns in the widest sense seems established, but the common stock from which they actually arose is still unknown. The Equisetales manifestly attained their greatest development in Palæozoic times; and the same thing is true of the Lycopods or club-mosses.

Flowering Plants

The cycads are now a small family with perhaps a hundred species occurring in tropical and sub-tropical regions, but nowhere being a dominant feature of the vegetation. A few become as large as small trees, and live to a great age; and some are a little like short palms. Throughout the family the male fruit is a cone; and in all the genera except one (cycas) the female fruits are likewise cones. The whole order is very primitive in habit; and its method of fertilization is shared only by the ginkgo or maidenhair tree. These primitive cycads, however, had an immense development after the carboniferous, during the Mesozoic era, right up to the Cretaceous period. Then in the Lower Cretaceous appear the Angiosperms, the flowering plants. By the time the Upper Cretaceous period arrived they had already swamped all other vegetation and had assumed the dominant position which they hold in the plant kingdom to-day. "Thus," says Scott, "they are isolated structurally from the rest of the vegetable kingdom while historically they suddenly appear, almost in full force, and apparently without intermediaries with other groups. To quote Darwin's vigorous words, 'The rapid development, as far as we can judge, of all the higher plants within recent geological times is an abominable mystery'. . . ." He thought that development might have perhaps gone on slowly in some isolated and lost continent—Suess's Antarctica: but though the idea of an Angiospermous invasion has been revived, it has no evidence to support it.[1] Light

[1] F. W. A. Miquel (translation of article in "Journal of Botany," 1869, p. 101) suggested that the advent of sucking insects favoured the development

has come from another quarter. In all the older Mesozoic rocks, the cycads were almost as prominent as the trees of to-day. Most of them are like recent cycads—except in one respect. The fruiting is not the same. The ancient cycads had a far more elaborate reproductive apparatus than their descendants. The predominant Mesozoic cycads were the Bennettiteæ. They are like the stunted cycads of later times, but had this elaborate reproductive structure, and exhibited numbers of lateral fruits like large buds on their stems near the bases of the leaves. For many years Wieland has been working on fossils derived from the Mesozoic beds of Maryland, Dakota and Wyoming,[2] with the result that these curious fruits are now regarded as being allied to the flowers of the Angiosperms. The Angiosperm with which Wieland specially compared the fossil type, was the tulip tree, and (Scott agrees) there is a remarkable analogy with the magnolia-like flowers and those of related orders like the water-lilies. "It is difficult to resist the conviction that the ancestry of the Angiosperms, so long shrouded in obscurity, is to be sought among the cycad-like plants which dominated the flora of the world in Mesozoic times." If, as now seems probable, the Angiosperms were derived from ancestors allied to the cycads, it would naturally follow that the Dicotyledons (plants springing up with two leaves) were first evolved. The Monocotyledons (plants springing with one leaf, like the grasses) would then have to be regarded as a side line from the two-leaved stock; though as far as we know the Monocotyledons, though always less numerous than the Dicotyledons appeared very little, if at all, later.

of flowering plants. The same suggestion was made by Laporta, to whom Darwin wrote in 1877 approving the suggestion (Darwin, "Life and Letters," IV, p. 285). The re-clothing of an island with vegetation has of late years been witnessed in the case of Krakatoa.

[1] G. R. Wieland, "American Fossil Cycads," Carnegie Institution, Washington, 1906.

CHAPTER XVIII

THE ANIMAL KINGDOM

Primitive forms and classification—Descent of the Ammonites—Vertebrate origins—Reptiles and birds—Mammals—Descent of the horse and elephant—Decay of races.

PROVISIONALLY it is possible to say when and where certain types of animal life began, and when and where they left off: but here precision ends. Although resemblances between two forms of life which were contemporary with one another or which succeeded one another may suggest relationships, the connexion is very often obscure and very often doubtful; so that while it is possible to draw up a rough table[1] indicating the eras in which successive forms of life appeared, flourished, or disappeared, the relations of these forms of life to one another cannot be assumed.

[1] APPEARANCE OF ANIMAL GROUPS IN GEOLOGICAL TIME

Invertebrates	Protozoa	Cambrian to Recent
	Porifera	,, ,,
	Cœlentera	,, ,,
	Echinoderma	,, ,,
	Annelida	,, ,,
	Arthropods	,, ,,
	Brachiopods	,, ,,
	Polyzoa	Ordovician to Recent
	Mollusca	Cambrian ,,
Vertebrates	Ostracoderma	Silurian and Devonian only
	Fishes	Silurian to Recent
	Amphibia	Carboniferous to Recent
	Reptiles	Permian to Recent
	Birds	Jurassic to Recent
	Mammals	(? Trias) Jurassic to Recent

The motility of animals was all against their standardization. Plants remained comparatively immobile and subject for ages to similar conditions. Animals by means of their organs of locomotion had continents—and perhaps by way of land-bridges—hemispheres to wander over. Thus the type was subjected to vastly different kinds of environment. Unsuited in one place it was suited in another. In one place (like rabbits in Australia or the English sparrow anywhere) it found so congenial a habitat that it multiplied out of all knowledge; and with increasing numbers it may have attained an increasing capacity for variability. Thus from the first the mutations of animal species were assured; they have, in the mutilated geological record, become bewildering. It is more profitable in the present state of knowledge to note the advance, pause, and decline of species, than to attempt to trace closely the conversion of one species into another.

It is possible none the less to trace the primitive ancestors, and to draw plausible conclusions of the line of descent in more than one species; and there are enough "links" to justify the belief that in all cases the life of one geological period has passed by a natural process of descent into the next succeeding period. The long-extinct class of organisms known as the Trilobites are extremely instructive in this respect. So far as is known they are found only in the Palæozoic rocks, though there are so many types among the Lower Cambrian as to give assurance that they must have been developing long before that era. In the Cambrian and in the succeeding period, the Ordovician, the Trilobites arrived at their period of greatest abundance; then followed a long, slow decline ending in complete and final disappearance before the end of the Permian, the last of the Palæozoic series. But the newly hatched and tiny trilobite larva is believed by some writers to be very near to the primitive larval form of all the Crustacea that have succeeded it. In

the Cambrian rocks, too, is found an extinct Echinoderm (Cystidea) which there is good reason to believe is the ancestor of all the star-fishes, brittle-stars, sea-urchins of all the ages since.

It is among these fixed and sluggish animals that we should expect least variation and the longest continuance. Among the Molluscs (or shell fish) the life history and the ancestral history of some forms have been worked out in a wonderful way. The Lamp-shells or Brachiopods also date from the Cambrian. They are not extinct, though they are greatly reduced now; but in Palæozoic seas they were incredibly numerous. Great masses of ancient limestone are often composed almost exclusively of their shells and their variety is in keeping with their abundance. The lines of their descent are being worked out. All Brachiopods form first a tiny embryonic shell called the protegulum; and this is believed to be the ancestral form of the whole group. The life history of a recent brachiopod will indicate the stages of its ancestral history.

Descent of the Ammonites

Among the Molluscs none is of greater interest than the extinct Ammonite, a cephalopod whose shell, curled like a ram's horn, is perhaps of all fossils the one earliest recognized by the beginner in geology.[1] They possess great geological importance because they are eminently characteristic of Jurassic times, and, in the geological phrase, they fix the stratigraphical horizon of that epoch. They arise in the Devonian where, as Ammonoids, they appear in their primitive forms. They appear in the Carboniferous and in the Permian.[2] But it was not till Triassic times that this great order assumed the importance which it maintained all through the Mesozoic ages. In the Triassic epoch more

[1] Sir A. Geikie, "Text Book of Geology," Vol. II, pp. 108-9 (4th edn).
[2] Chamberlin and Salisbury, "Geology," Vol. II, p. 653.

than 1000 species have been described. In the open seas which then spread over Southern Europe, and extended into Asia, into America, and even into the Arctic regions, there flourished an altogether extraordinary profusion and variety of cephalapod life. They culminated in the Jurassic. A slow decline began in the Cretaceous seas; and at the end of that period they had gone altogether. But in the rocks of the Mesozoic era, wherever conditions are favourable, these shells are stored in countless multitudes; and no fewer than 5000 species have been described. Not all the units of the huge assemblage of the Ammonites can be grouped in family kinship: but several beautiful series have been already determined. As a final phase in the history of the Ammonites there appear many so-called abnormal genera, in which the shell is irregularly coiled, or more or less uncoiled, in some forms becoming actually straight. It is interesting to observe that some of these genera are not natural groups, but are each derived from several distinct ancestral genera, which have undergone a similar kind of degeneration.[1]

Vertebrate Origins

The foregoing is one of the triumphs of comparative fossil-study. With the approach of periods in which land-forms, and the relics of the more mobile animals were preserved the difficulties begin. In the Silurian, for example, the Ostracoderms, which resemble fishes in general form, begin to appear; and there are scales and spines which belong to a creature like a shark. These are the first recognizable vertebrate or backboned animals. Whence did they spring? We have noted the decay of the Trilobites during this period. Their place, in point of numbers, seems to have been taken by the Eurypterids—a group which includes

[1] W. B. Scott, "Darwin and Modern Science," "The Palæontological Record," p. 198.

ancient representatives of king crabs and marine scorpions. They were most abundant in the Silurian and after reaching their largest size almost immediately afterwards gradually dwindled into insignificance. In other words there was a great outburst of Eurypterid life, just at the time when the first backboned animals arose. It is suggested that when the Eurypterids were at their prime, and most likely to vary, some spiny variation of them assumed a form resembling the first backboned animal. In the succeeding Devonian period fishes distributed themselves widely over the northern hemisphere and "then[1] began suddenly a remarkable impulse towards the production of lung breathers, which is noticeable not only in Europe and North America, but also probably so far away as Australia. In the middle and latter part of the Devonian period most of the true fishes had paddles making them crawlers as much as swimmers . . . many of them were unlike true fishes, while agreeing with lung breathers, and some were like both fishes and lung breathers." (The few survivors of these to-day have an air bladder which is in effect a lung.)

The characteristic fish of the Devonian therefore approached nearer to land animals than any fish since; and it is noteworthy that about this period the first amphibians appeared. In the next period (later Carboniferous) they become firmly established, and between that period and the Mesozoic era they seem to have spread all over the globe. Their remains have been found in Europe, Spitzbergen, India, South Africa, North and South America, and Australia. These primitive amphibians (Labyrinthodonts) were therefore a roving and vigorous race; though, dwelling as most did in marshes, they kept more or less to what Woodward calls the salamander pattern. Only in the later periods of the Palaeozoic era did some of the smaller of them

[1] Dr. A. S. Woodward, "Address to Geolog. Sec. British Assoc.," 1909, p. 3 of reprint.

resemble lizards or snakes. Among them suddenly arose the reptiles, not, however, at first replacing the amphibians, but being of rather secondary importance till the Mesozoic era dawned.

Reptiles and Birds

Then the reptiles came into their kingdom. They radiated in two ways; the Conservatives clinging to the habits of their marsh-dwelling ancestors; the Peregrenines, who were the majority, becoming so like mammals that we seem to perceive the struggle of a life force which aims to reach the higher level of a warm-blooded grade. There is not much doubt that mammals arose before the middle of the Mesozoic era, though they were far from at once replacing the lower race, or from exterminating it by unequal competition. Reptiles held their own on all hands through the greater part of the Mesozoic era; it was not till the Tertiary era that mammals began to predominate.

The first of the birds appears in Mesozoic (Jurassic) times. The oldest known fossil bird was found in the Lithographic slate of Solentrofen, Bavaria. In this primitive type—the Archæopteryx, of which the first specimen to be discovered is in the British Museum of Natural History—we have a valuable link in the chain of evidence as to the origin of the birds. "This bird," observes W. P. Pycraft,[1] "more nearly resembles the reptile than any known form. The two specimens in Berlin and London agree in having the jaws armed with teeth and a long tapering lizard like tail, but this like the rest of the body bore feathers. . . . We have in this primitive type not only a remarkable link in the chain of evidence as to the source from which birds derived their origin, but also a most valuable key to some avian characters which would otherwise have had to be explained as mere conjecture. In so far as the reptilian characters are

[1] "A History of Birds" (Methuen), p. 35, et. seq.

concerned the principal features are the teeth and tail. . . . Not unfortunately till the Cretaceous period do we again meet with bird remains, and these have now all become stamped with avian characters in all save that the jaws still bore teeth." Woodward remarks that towards the end of the Triassic period rose a race of small reptile Dinosaurs of the lightest possible build, which exhibited many features suggestive of the bird skeleton: "so it is probable that this higher group also originated from an extremely restless early community of reptiles, in which all the variations were more or less in the right direction for advancement". So closely do the birds and reptiles agree indeed that Huxley included them together under the term Sauropsida.

Mammals

As the characteristic forms of life of the Primary rocks were Mollusca and Crustaceans together with some strange fishes and amphibians; and the Secondary rocks were characterized by the first appearance of many strange forms of Reptiles; so the Tertiary rocks are distinguished by abundance of Mammalia. These are divisible into two classes: (1) The Archaic primitive mammals, partly descended from ancestors in the Age of Reptiles, and having hardly any modern descendants, and (2) Mammals which are the ancestors of the modern mammals.

The exceptions to the generality of the foregoing classifications are few. Of the myriads of Reptiles that characterized the Secondary era, only two of the nine orders into which they have been subdivided have been found as far back as the Permian, the latest of the Primary formations. One of these most primitive reptiles has a near ally in the strange lizard-like Hatteria still surviving in some small islands off the coast of New Zealand: while others which seem to form connecting links with the earliest mammals may be the ancestral form from which have descended the unique

types of the lowest living Mammalia, the ornithorhynchus and echidna and platypus of Australia.

These hybrid ancestors were first discovered in the Karoo formation of Cape Colony, but have been found since in a few places in India, Europe, Southern Brazil, and North America, always in the latest of the Primary strata, or the earliest of the Secondary strata. At the beginning of this century Prof. Amalitzky of Warsaw found a rich deposit on the banks of the River Dwina in Northern Russia; and many of his astonishingly perfect remains are found to be almost identical with those of South Africa; others quite distinct though allied. In North America their fossils were also present in great abundance. But the truly remarkable thing about these curious reptiles whose resemblances to lower and higher orders of life stretch in both directions, is "that some hundreds of species of varied form and size, herbivorous and carnivorous, should have gradually developed, arrived at maturity, and completely died out during the comparatively short periods of the Permian and the Trias."[1]

Thus though the Tertiary period is called by universal consent the Age of Mammals and is believed to have ranged over a period of 3,000,000 years, the ancestral origins of the mammals must be placed perhaps 15,000,000 years farther back. Their intermediate ancestry is not less perplexing. About the middle of the nineteenth century small mammalian jaws with teeth were discovered in what was known as the dirt-bed of the Purbeck (Jurassic) formation at Swanage, and more recently very similar remains were found in beds of the same age (and also in the Cretaceous) in North America. They are supposed to be primitive insect-eating Marsupials or Insectivora, and were quite small. They occur through the whole range of the Secondary period but their remains are exceedingly scanty, and the animals themselves

[1] "The World of Life," by A. R. Wallace, p. 200 (Chapman & Hall), 1910.

appear to have made scarcely any progress in that enormous lapse of time. Yet directly the Tertiary era dawns, the Mammalia became abundant and of fairly large size. A. R. Wallace suggests[1] that the break between the Secondary and Tertiary beds was of such enormous duration as to afford time for the simultaneous dying out of numerous groups of gigantic reptiles and the development in all the large continents of much higher and varied mammals. But this does not carry us much nearer a solution of the problem of the disappearance of the reptiles. They survived in large terrestrial and aquatic forms to the very close of the Cretaceous; giant sea lizards or Mosasaurs in the sea, and herbivorous and carnivorous dinosaurs on land. It has been said that their disappearance prepared the way for the evolution of the mammals[2] by which is meant no doubt that their removal as competitors for the food supply gave the mammals a better opportunity to survive, to spread, and to develop.

Nature began afresh with the small unspecialized members of the warm-blooded quadrupedal class slowly to build up out of the mammal stock the great animals which were again to dominate land and sea. At the close of the Cretaceous, though many reptiles were extinct, there were some which lived still in the climax of specialization and grandeur: and the mammals who moved among them were without exception of small size, of humble and inconspicuous forms. Then comes the great change. Some geologists have interpreted the disappearance of the reptiles as an illustration of the failure of the life-force which having served to carry on a species to its highest point of development or specialization thereafter flickers to extinction. Others, among whom is Dr. A. R. Wallace, attribute the change to a world-wide alteration of atmosphere—an enrichment or withdrawal of its carbonic acid or its oxygen. There is

[1] "The World of Life," by A. R. Wallace, p. 191.
[2] Dr. Fairfield Osborn, "The Age of Mammals" (Macmillan, 1910), p. 97.

some plausibility in finding a parallel between the atmospheric conditions at the end of the Secondary era, with those which were in existence at the end of the Primary era. The growth of vegetation in the Carboniferous period locked up carbonic acid which had been taken out of the atmosphere. The great formations of limestone during the Cretaceous period may similarly have diminished the proportions of this gas in the atmosphere, and thus have rendered both the air and the water better fitted for the purposes of the higher, warm blooded, and more active forms of life.

At the same time this supposition is merely a speculation. The positive factor is not the cause but the effect. Whether there was, or was not, a gradual change of conditions at the close of the Cretaceous, we have no doubt that the world-wide effect was the same. The giant reptiles both of sea and of land fade from existence. Reptiles are so sensitive to temperature that it is natural to attribute this extinction to a general lowering of temperature or refrigeration,[1] but the flora shows no evidence of this either in Europe or America; nor is there any evidence of any great geographic cataclysm on the surface of the Earth, for the plant life transition from one Age to the other is altogether gradual and gentle.[2]

The Age of Mammals

It is not unlikely that in the future, light will be thrown on this and similar extinctions, apparently world-wide, by a consideration of the causes of extinction of the animals of the Age of Mammals. In geological nomenclature, the term *Cainozoic Era*, the Age of Recent Life, has generally replaced the older term, Tertiary, which merely signifies the third period in the history of life. The Cainozoic is sub-

[1] "The Age of Mammals," by H. F. Osborn, *op. cit.* p. 98.

[2] Knowlton and Stanton, "Bull. Geol. Soc. Amer." Vol. VIII, 1897, pp. 127-56.

divided into two Periods, Tertiary and Quaternary, and six Epochs,[1] beginning with the earliest, the Eocene.

Tertiary Period

Eocene. Characterized by the first appearance of many of the ancestors of the modernized mammals and the gradual disappearance of many of the archaic types of mammals characteristic of the Age of Reptiles.

Oligocene. Characterized by the appearance of many existing types of mammals and gradual disappearances of many of older types.

Miocene. An earlier state of modernization in which lived many mammals closely similar to existing forms.

Pliocene. A vast modernization of the mammals in which all the existing orders and families are known, as well as many of the existing genera, *but few or no existing species.*

Quaternary

Pleistocene. A life period in which the majority of the recent form of mammals appear, and in which occurs a great natural extinction of earlier form in all parts of the world.

Holocene. Recent time, characterized of the world-wide destruction and elimination of mammals.

It must be remembered that in this great period of time, estimated at 3,000,000 years, the changes at the face of the Earth were very great. Continents were severed, were joined, were severed again. The Rocky Mountains had begun their elevation at the end of the Age of Reptiles.

[1] Osborn, *op. cit.*

But at the beginning of Eocene time, the great mountains of the Pyrenees, the Alps and the Himalayas were yet unborn ; they were level surfaces washed by the sea. Not till the end of the Oligocene did the mighty system of the Swiss Alps begin to arise ; and Central Asia was even then plain and upland. Only during the Miocene the Himalayas the greatest of existing mountain chains began to uplift themselves to "their fellowship with the sky".

There was time in this vast stretch of events for the life-story of a Continent to alter ; for the life of one Continent to become merged in another. The life-history of the Mammals having begun, and its continuance having been favoured by the general conditions of the globe, it altered according to certain evident laws. The first of them is the "Law of Adaptive Radiation".[1] According to this law each isolated region, if large and sufficiently varied in its topography, soil, climate, vegetation, will give rise to diversified mammalian fauna. From primitive central types branches will spring off in all directions, with teeth and feet and paws modified to take advantage of every possible opportunity of securing food, and in adaptation of the body, limbs and feet, to habitats of various kinds. The larger the region and the more diverse the conditions, the greater the variety of animals which will result. From the small insectivorous or omnivorous early mammals, with simple short-crowned teeth, and short feet with claws, the later mammals would diverge in four directions. They would become diggers, or swimmers, or swift moving, or adapted to tree life. No instance has been found of a mammal having been transformed from an aquatic to a land type ; it is always the reverse. Nor have the diggers or runners ever gone back to the slow-moving types, though the tree climbers sometimes seem to take up terrestrial habits.

[1] Osborn, "Amer. Naturalist," Vol. XXXIV, 1902. pp. 353, 363.

The second law is that of "Analogous Evolution," a term which carries its own explanation, and which may be broadly interpreted by saying that mammals in their adaptation to similar conditions of habitat or environment in different parts of the Earth, have repeatedly converged or come to a resemblance in their external form, and more or less in their internal form, as well as in separate structures.

The third law is the "Law of Irreversibility of Evolution". Thus in adapting itself to its habitat or environment there may be a profound modification of form, by which (for example) two of the toes of an animal may become one. These lost parts are never re-acquired, nor can such profound modifications of parts be overcome. A *specialized* organ can never again become *generalized.*[1] Lost parts are irretrievable. It follows that while the conditions of life may be recurrent or reversible, the conditions of adaptive structure are not reversible. This extreme specialization, accompanied by great enlargement of certain parts, and the great reduction of other parts, may place a mammal in a blind alley of structure. It cannot alter itself to meet a new environment. It cannot reduce its unnecessary and no longer useful bony parts; it cannot get rid of its trunk or its tusks. Its previous advantages may become disadvantages. They may become a cause of extinction.

In the Age of Mammals there were several crises of extinction. Osborn[2] remarks that in that Age the great law of mammalian improvement through the *elimination of of the least fitted* becomes less sweeping as time goes on. He divides the Age into what he calls Faunal Periods. There is evidence that at the outset of mammalian history, all the great continents were not only richly supplied with mammalian life, but that during the preceding Age of Reptiles important migrations and interchanges of mammalian life had taken place, establishing a cosmopolitan

[1] Osborn, *op. cit.* p. 34. [2] *Ibid.*, pp. 172-4.

distribution of the more primitive forms. These interchanges and migrations, distributions and re-distributions, continued through the various Faunal Phases.

In the First Phase, the Basal Eocene, there were Archaic Mammals only. In the Second Phase, the lower Eocene, Archaic and Modern Mammals were mingled, and the old Arctic region appears to have been warmer. In the Third Phase Europe and America were separate. Then in the Oligocene, when Europe and America were united again, the Archaic mammals became extinct. In the next phase, the Miocene, Africa sent its animals through Europe to America, and Asia sent migrants also. In the Sixth Phase, the Pliocene, North and South America exchanged mammals. In the last Phase, the Pleistocene, there was a world-wide extinction.

Summing up these periods in another way : the Eocene witnessed extinction of the *Orders* of Archaic mammals, the late Eocene the extinction of inadaptive *families* of mammals ; the Miocene and Pliocene, the extinction of inadaptive genera ; the Pleistocene, the extinction of highly adaptive kinds of mammals in certain parts of the world, both of genera and species.

Even adaptiveness, it can be seen, does not always save a type, but possibly that is only another way of saying that the extinguished type is not adaptive enough. The general causes of extinction are fairly well recognized. The archaic mammals had usually very small brains. This limited brain power placed these quadrupeds at a disadvantage in competition with the higher placentals. Better brain power with its consequences of alertness, quickness, resource, enables a type to make the best of the conditions by which it is surrounded, and when there is competition for the food supply, to remain victorious in the contest. Modern quadrupeds differ widely in this regard : on the western plains of North America, for example, the horses by their resourcefulness

save their lives where cattle perish. A million years earlier the ancestors of the horse measured their powers against the extinct Phenacodonts—which had teeth as good, but smaller brains and inferior feet—and survived them. Teeth and feet capable of appropriate development are the other associated factors in survival. Where the evolution of an animal runs to the development of tusks and horns (useful no doubt in fighting) the grinding teeth are apt to show arrested development. Bulk alone does not forewarn extinction ; it is fatal chiefly when poor feeding mechanism and low brain power go with it. The low brain power may handicap the females in caring for their young, as well as in caring for themselves. On the whole brain power seems to be the most useful quality in survival, but in some cases as in the extinct rhinoceroses and mastodons it failed. Changes of climate, moisture, dessication, temperature ; the introduction of parasites ; the extension or limitation of land areas with the corresponding alterations of food supply ; the substitution of insular for continental conditions—are all potent causes in the extermination in certain localities and of the survival sometimes of very primitive forms.

The source of the world's supply of mammals, the great homes, centres, or continents, from which the orders evolved and took on their distinctive forms, remain a problem not yet thoroughly worked out. But the broad outlines of a satisfactory generalization are being gradually worked out. It was for long reasonably supposed, that as the greater land masses of the globe are in the north, the theatre of evolution of the mammals was in that hemisphere, and that the mammals spread thence to the south. There was, it was thus supposed, a grand northern centre of evolution and dispersal both of plants and animals. Even if this hypothesis be extreme the fact remains undisputed that the northern portions of Europe, Asia and North America

formed the greatest creative centre, probably during the Age of Reptiles, certainly during the Age of Mammals.

But this eclectic hypothesis has been disturbed by the discovery (very largely a twentieth century discovery) that Africa was also an important centre of mammalian evolution. A most welcome verification of this theory was obtained in 1901 when Dr. C. W. Andrews[1] and Mr. Beadnell announced the discovery of numerous fossil land mammals in Upper Eocene and Lower Oligocene strata of the Fayum district in Egypt. One discovery followed another, and Africa, so far from being a continent which obtained its mammals from the north, was shown to have been a great breeding place of animals which subsequently wandered into Europe, as well as of other hitherto unknown types. The ancestors of the Proboscidea (mastodons and elephants) and the Hyracoidea (ancestral conies) were successively found here; as well as the giant *Arsinotherium*, a large herbivorous quadruped with a pair of great horns on the front part of the skull. The Sirenia or sea-cows were traced back to their primitive forms, and then the ancestors of the archaic whales, or Zeuglodontia, a group also previously discovered here, were traced back to their early stages of evolution.

Still more lately a belief first put forward by Sir Joseph Hooker and more fully by Rutimeyer, the Swiss palæontologist, that there was a great Antarctic continent of milder and more equable climate, which was a centre of evolution and distribution of life, has received much support and South America has been conceived as having been a theatre of evolution comparable with Africa. In this way South America is pictured as having a close early kinship with North America, but a more ancient kinship with Australia through an Antarctic continent.

[1] Cf. C. W. Andrews "A Descriptive Catalogue of the Tertiary Vertebrata of the Fayum, Egypt." London (1906).

CHAPTER XIX

THE DURATION OF MAN

Glacial epochs and river terraces—Pithecanthrcpus erectus—Neander and Spy skulls—The aspect of primitive man—Cromagnards or Reindeer men—Weapons and implements of Palæolithic man—Eoliths—Europe in the Palæolithic age—Life of Palæolithic man—Classification of races—Neolithic man—The future of the planet.

AMONG the imperfections of the fossil record none is more perplexing than that which relates to the period and descent of man. The scarcity of the remains and the diverse interpretations which can be put on the evidence are illustrative of the difficulties in drawing trustworthy inferences from the fossil remains of other animals incomparably less recent. The evidence is of two kinds; that which is afforded by human remains; and the indirect evidence of the places where they were found and of other relics in their neighbourhood. In neither case is the evidence incontrovertible. Some of the remains may not be indubitably human. The corroborative evidence may be in dispute.

First in regard to the age of the remains. They belong almost beyond question to the Pleistocene or Quaternary period, in which occurred what we may continue to call the great Ice Age. According to the most generally accepted authority, Penck,[1] there were four glacial periods in the Ice Age, each of them interrupted by genial non-glacial periods.

[1] A. Penck and E. Brückner, "Die Alpen im Eiszeitalter," Leipzig, 1901-1908, issued in parts, not yet complete, p. 1172.

Part of the evidence on which Penck depends, is afforded by the existence of river terraces in valleys once occupied by glaciers. The age-long advance of a glacier would excavate a valley and lay up materials for a terrace on its sides. In an age-long period of glacial retreat, the terrace would consolidate its position and the valley would become spread with the sands and gravels of river erosion. This process has proved to have been four times repeated. There is corroborative proof of the truth of the inference. "The four terraces are ruled, as it were, across the last page of terrestrial history. They are datum lines ruled, as it were, across the last page, which enable us to divide the Pleistocene or Quaternary epoch into eight ages, the first, second, third, and fourth glacial ages and a similar succession of genial ages. We are thus provided with a chronological scale to which we can refer the more important events in the early history of the human race" (Sollas).[1] It is in the gravels contemporary with these terraces that human remains and evidences of human activity are sought. Among the evidences offered by the gravels are flints embedded in them which in some cases may have been made by man and used by man as weapons or implements. A question which is of the greatest importance, and which is continually re-awakened by new discoveries, is whether any of these weapons or implements can be assigned to a period before the Pleistocene. More than once it has been asserted that this or that skull has been found in a Miocene or Pliocene bed; but the evidence has not proved satisfying. In the instances of those fossil skulls which are incontrovertibly of human origin we are now able, however, to distinguish six stages in the history of Palæolithic man: The Chellean,

[1] W. J. Sollas, "Palæolithic Races," "Science Progress," 1908-1909. Dr. James Geikie recognises six glacial epochs and some American geologists seven. Prof. Marcellin Boule recognizes evidence of only three.

Acheulean, Mousterian, Aurignacian, Solutrian and Magdalenian, some of these being capable of further division into two or more sub-stages. Behind these dynasties lie the skulls and other remains of creatures which possess indeed human characteristics, but possess simian characteristics as well.

Pithecanthropus Erectus

One of the best known is the skull which was found in Java by Dr. Dubois in 1892, and which has been assigned to a primitive form of ape-like man called *Pithecanthropus erectus*. A monument marks the finding place near the village of Trinil of this earliest man; whose skull has been examined by every anatomist in Europe; and the place was revisited in 1906 by Madame Selenka and M. Carthaus. The expedition found no more skulls, but they found indications of primitive bone weapons, and, it is said, relics of the fire that the Trinil man had lighted. When the skull was first found it was said by Dubois to be of the Pliocene period. That is no longer believed; it is now asserted to belong more probably to the Quaternary epoch.[1] But its age is not the sole point in dispute. All anatomists are agreed that the Trinil skull was that of some creature like both man and ape; but how far its owner had climbed the ladder between the lower and the higher form is a matter of dispute. Judged by its receding forehead the creature was less intelligent than a chimpanzee. But after all the brain counts for more than its casing. The interior capacity of the skull cap of *Pithecanthropus* has been as carefully measured as it can be; and the cavity has a volume of 850 cubic centimetres. This is less than that of any healthy human being, for the human capacity never falls below 880 cubic centimetres; but it is higher than the cranial capacity

[1] "Neues Jahrbuch f. Mineral," Stuttgart, 1907, p. 256, by Prof. Volz of Breslau, who has made a special study of the district.

of the higher apes, which is not known to exceed 600 cubic centimetres. If we judge by these criteria, the Trinil "man" must have been very nearly a man. There is reason for believing that it could speak. The faculty of speech resides in a fold of the brain called Broca's area. The Trinil man's speech area is twice as great as that of the anthropoid apes, though it is only half as large as that of man. The skull was not the only bone found belonging to him. The others lead to the supposition that he walked erect and that his height was about that of an average Englishman. Whether he was the highest representative of the human race of his time is open to doubt. The anthropoid apes had certainly preceded him, for they are found in the Middle Miocene, as are the true Old World monkeys, and the lower monkeys. In the Miocene the mastodon had not then been replaced by the elephant; the horse had still three toes.

Neander and Spy Skulls

A skull which is of still greater historical interest is the Neander skull which was found in a cave sixty feet above the river Dussel where it flows through a ravine called the Neanderthal. It was embedded in the hard loam of the floor where it must have lain since the river flowed at the cave's level. It was damaged in the course of being dug out, and is so unlike the skull of any existing human being that when it was first discussed, half a century ago, Huxley was exceptional in declaring it to be the skull of a man. A number of remains have been found since which confirm his judgment, and the Neanderthal skull has given its name to the earliest recognizable race, the Neanderthal men.

Other remains found since of the same kind include two nearly complete skeletons from Spy, the skulls of which are, however, imperfect, various fragments representing, perhaps, a dozen ancient men from Krapina in Croatia, and a skull

from a cave in Gibraltar, which has been in the Royal College of Surgeons for more than forty years. Other fragments, such as jawbones, have been discovered in various places in Europe during the last half century, and from them a reasonably accurate idea of what the Neanderthal man was like has been put together. More recent discoveries have confirmed the conception. A well-preserved skull of Neanderthal type was found at La Chapelle aux Saints in the Corrèze district of France in 1907; and it was part of the remains of some ancient man who had actually been buried in a primitive tomb—probably with provisions to speed the departed on his way. This skull is of great importance because it clamps together, as one might say, the speculations founded on the incomplete relics which had preceded it. The "Corrèze skull" has another great point of interest which is that, according to Prof. Marcellin Boule of Paris who has carefully examined it, it has a brain capacity of 1600 cubic centimetres. If that measurement is to be regarded as precise then the Neanderthal man had a brain cavity as large as, perhaps larger than, that of the modern European. The regions of the brain were, however, differently distributed.

Two other skulls of the same type and race were dug out in the valley of the Dordogne near Le Moustier in the years 1908 and 1909 respectively, and at Heidelberg a jaw was found in 1909 which was at first attributed to an earlier age than that of the Neanderthal men. Indeed, like other skulls, it was at first said to belong to the Tertiary Era. That speculation has not been maintained. The Heidelberg skull has been assigned to the Quaternary Age; though it is claimed for it that it belonged to a race which possibly preceded the Neanderthal men, and at any rate was of an earlier time than the skulls and skeletons found near Le Moustier. The Le Moustier type of skull has given its name to a sub-divisional era of the Neanderthal men (the

Mousterian Age). The Mousterian men lived during one of the colder epochs. The race earlier than themselves who have left behind them, if not their skeletons, then at any rate some of their flint weapons, are presumed to have known a milder climate. They are called the Chellean men after a French township where flints associated with them were discovered. Dr. Schoettensack believes that the Heidelberg jaw belongs to an older and stronger-jawed race than the Neanderthal men, and is supported in this opinion by Sollas, who remarks that though the skull has some ape-like characteristics it is beyond doubt human.

Aspect of Primitive Man

The face of primitive man to which we naturally turn to gain our first impression of him was unlike that of any existing race, though Dr. R. S. Lull [1] says that occasionally something of his type arises in modern man, notably in St. Mausberg, a mediæval Bishop of Toul, and in Lykke, a scientific Dane, as well as among Australian aborigines and Melanesians. These are ancestral throw-backs. Neanderthal man had a skull which looked on from above had something approaching the pentagon form.

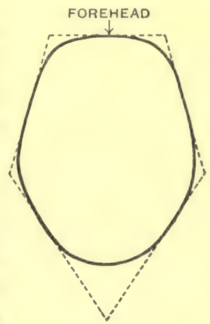


Fig. 24.

Looked at from the front the face was remarkable for the great overhanging brows, a kind of ridge over the deep-set eyes, which had very large sockets. The forehead over the heavy thick ridge above the eyes receded sharply. The nose was large also, with very broad nostrils, and probably was like a great snout. The upper lip was very long; there was a great distance from the base of the nose between the eyes,

[1] "Restoration of Palæolithic Man," R. S. Lull, "American Journal of Science," Vol. XXIX, No. clxxix., Feb., 1910, pp. 171-2.

to the mouth, but the chin did not jut forward. Rather it receded, though the jaw was very strong and strongest where now it is feeblest, in the region of the strongly developed wisdom teeth. Neanderthal man was not tall. Lull describes him as a man of low stature, standing only 5 feet 3 inches in height, but of great physical powers as indicated by the robustness of the limb bones and especially of the joints. Great power is shown in the upper portion of the trunk and in the arms. This man did not walk quite upright. His knees were a little bent as the curved thigh bones indicate; and the inward curve of the backbone so characteristic of modern man is but feebly developed. In spite of his strength he walked rather like a child or an old man bent with years. The lower part of the leg from the knee downward was relatively short, and the great toe jutted out a little, though it had long since lost its resemblance to the toe of the apes. Gone too was the heavy paunch of the anthropoid ape, for man had ceased to be a vegetarian. He was a strong and crafty hunter, for the remains of various animals which he slew for food are found entombed near his own remains, and he was clean cut and strong, like the North American Indian. The race nearest to these men to-day is that of the Australian aborigines. In stature they do not differ widely, in facial appearance they have some resemblances, and the capacities of their brain pans were very much alike. It is a point to be noted that the Australians are like the Europeans of to-day in being wavy haired (as distinguished from curly haired like the negroes or straight haired like the Indians); and they further resemble us in the abundant growth of beard.

The Cromagnard Men

Following the Neanderthal men came the Cromagnards, or Reindeer men, as Sir E. Ray Lankester[1] calls them.

[1] Articles on Neanderthal and Cave men in "Science from an Easy Chair" (Methuen).

A RESTORATION OF PRIMITIVE MAN
By Dr. R. S. Lull of Yale University
(Photograph by Dr. R. S. Lull's permission)

The first skulls of their race were found at Cro Magnon in Central France. Some of the men of this race were very tall—one of the skeletons from the Mentone Caves is that of a man 6 feet $3\frac{1}{2}$ inches in height. They had good brain capacity; the drawings which they have left in caves, and their beautiful carvings prove that they had artistic ability of a well-developed kind. They had thick skulls, though they had not the enormous thickness about the forehead of the Neanderthal men; they had fine narrow noses, and strong jaws, though the jaw was not overdeveloped as in the modern negro. They were a long-headed rather than a round-headed race.

Recent careful excavation of four caverns at Mentone by the Prince of Monaco, where a number of skeletons of that age have been brought to light, indicate the existence of another race. "In one of the caves,[1] and in a position showing them to date from the deepest layer of the Middle Pleistocene, a late Glacial Age, two complete skeletons have been found, which are obviously different from those of both the Neanderthal and the Cromagnard peoples. They have skulls which decidedly resemble that of the modern negro race, so that they have been definitely assigned to a new race hitherto unknown in European caves, and are spoken of as the 'negroid skeletons' and the 'Grimaldi race'. This is indeed a startling fact. . . . These skeletons suggest that already there was a negroid race in Africa, individuals of which had wandered north as far as the Maritime Alps." The inference from this discovery is that in that remote period there were already three great branches of the human race in existence—the negroid curly-headed race, the Neander men, and the highly developed Cromagnards. Later in time, the place of the artistic Cromagnards was taken by the Neolithic men, who could make flint weapons well, indeed better far than any of their predecessors,

[1] Sir E. Ray Lankester, "Science from an Easy Chair," p. 398.

but who were a dull race compared with Cromagnards. We possess as yet no indication whence these later Neolithic men arose and developed, nor who their contemporaries in other parts of the world were.

Weapons and Implements

From the evidence of the skulls we turn to that afforded by the weapons and tools which these primitive men left, the drawings which some of them made, and the relics of the animals which are presumed to have been contemporary with them. The flint weapons and tools are roughly divided into those made by the most ancient or Palæolithic men, and the much more finished acticles made by the Neolithic men, who continuing the story of man through what is called the Stone Age lead it to within the limits of historical record. But in a number of places forms of chipped flints have been found which are in several respects ruder than the flint implements and weapons which are accepted without cavil as the work of man. Among the places where these curious flints were found was Ightham in Kent. Here Mr. Benjamin Harrison found them on the top of plateaux of such an age that if they can be admitted as genuine human workmanship they would put back the first appearances of the human race beyond that of any skull yet found, and would assign it to the Tertiary period. These flint fragments were submitted to Sir J. Prestwich, and examples of them may be seen in the Natural History Museum. They are called Eoliths; and the dispute as to whether they are artificial or accidental has given rise to the Eolithic controversy.

They are not the only ones found. At Thenay fifty years ago L'Abbé Bourgeois discovered some such chipped flints in Tertiary (Oligocene) deposits, and the Thenay discovery may be regarded as the starting-point of the suggestion of the existence of Pre-glacial man. Since then chipped

flints have been found at Puy Cournay in Auvergne, where there is no doubt as to the date of the beds; they are certainly Tertiary; the one thing in dispute is the artificial character of the stones. It is a dispute in which the highest authorities have joined issue. One of the chief opponents of their artificial origin is Prof. Marcellin Boule. In the course of his investigations concerning flint forms, Prof. Marcellin Boule found a cement factory near Mantes where flints were "washed" with the materials of the cement and were subjected to severe collisions and impacts for about twenty-four hours before being flung into the factory's "waste". In this waste he affirms that he can find every variety of so-called Eolith, with all the supposititious marks of human handiwork — "bulbs of percussion," "pointed ends," "curvilinear notches," and "re-touched" edges.

On the other hand a large school of "prehistorians," of whom M. Rutot, who began by disbelieving in Eoliths, is a distinguished representative, stoutly maintain a belief in the artificial character of these flints; and they remark that M. Boule's case would be stronger if he could find flints resembling true Eoliths in places where they had *not* been subjected to such artificial treatment as that which the flints receive at Mantes. M. Rutot's positive method is undeniably scientific in character; for he endeavours to trace the resemblances between these Eolithic flints and those which (of later age) are admittedly Palæolithic tools or implements. It is impossible in the present stage of knowledge to arbitrate between the two schools of opinion, but while on the one hand Prof. W. J. Sollas remarks that no sufficient evidence has yet been obtained by the existence of man or his immediate precursors in any epoch before the Pleistocene" yet both this authority and Sir E. Ray Lankester affirm a belief in the artificial characters of some Eoliths.

Further examples of Tertiary chipped flints, which are disputably artificial in character, have been obtained by

various investigations from Olta near Madrid, from Burma, from East Norfolk, from Boncelles, and from the Karoo. We have already spoken of the chipped flints found by Harrison on the Kent plateaux. Prof. Rutot assigns them to the Tertiary Pliocene. But whether he is right or not, there are some reasons considered good by Prof. W. J. Sollas and other authorities for referring them to a period before the so-called Palæolithic Age; and, while the "Eolithic controversy" in all its bearings is still far from being settled, one may perhaps venture the opinion that, on the evidence, a race of men existed and have left relics of themselves before the time of the Lower Palæolithic Man.

Europe in the Palæolithic Age

Lower Palæolithic man comes equipped with various credentials; and Prof. Sollas has drawn a picture of Europe as this ancient race found it.[1] "The whole continent of Europe had enlarged its bounds and the Atlantic broke against a shore lying far to the west of the British Isles, along a line where soundings now show a depth of 100 fathoms. It looks as though the ocean had sunk 600 feet. The Irish Sea, the English Channel, and the German Ocean, thus deserted, formed wide valley plains, watered by many noble rivers. The Rhine, with its tributaries the Elbe and the Thames, swept in wide meanders to the north till it opened into the sea not far south of the Faeroe Isles; the Seine, gathering the waters of the south of England and north of France in its flow, continued its course through the fertile plains of the English Channel till it entered the Atlantic a hundred miles west of the farthest point of Brittany or Cornwall; and the deepest parts of the Irish Sea formed great fresh-water lakes stocked with ancestral salmon.

"In the south we might look in vain for the Adriatic, and

[1] "Science Progress," January, 1909.

in place of the Mediterranean we should discover two restricted inland seas, separated by a broad isthmus, which extended from Northern Africa, through Sicily, into Southern Europe.

"On the extreme east, Asia was probably united with America, across Bering Strait, by a tract of land which extended an unknown distance to the south, perhaps completing the arc of the Aleutian Islands, now represented on the map by a mere dotted line.

"On the extreme west and north an ancient bridge, afterwards to break up into Iceland and the Faeroes, was possibly still standing, and united Europe with Greenland and the east of North America.

"In some places, on the other hand, the sea penetrated farther into the land, as where the Arctic Ocean covered all the region of the gulf of the Obi.

"A traveller starting in this ancient world from the banks of the Thames could have made his way over the watershed formed by the Straits of Dover into France, and so through Italy and across Sicily into Africa, which would have then lain open to him from end to end. If instead of entering Africa he had turned to the left, he could have reached India by devious paths, the Malay peninsula, and the East Indies, which, unite here and there by land-connexions, would have taken him, with the help of a frail canoe, into Australia, whence he might have wandered into Tasmania.

"If he wished to visit North America he would have had, perhaps, a choice of routes, either by the Icelandic bridge or the Alaskan isthmus.

"Even before leaving England he would see strange sights by the way: great herds of elephants of an ancient kind (*Elephas antiquus*), the mightier predecessors, perhaps ancestors, of the mighty African elephant; he might witness, not without awe, the infuriated rush of the soft-nosed rhinoceros (*Rhinoceros leptorhinus* or *Merckii*), which bore a horn

sometimes as much as three feet in length; disporting itself in the rivers was that shy behemoth the hippopotamus, the mother animal swimming with her young upon her back; sometimes he might catch sight of the great sabre-toothed lion (*Machairodus*) making its stealthy spring, or hanging on to the flanks of a strayed elephant. A delightfully warm open climate might tempt the traveller to make his bed in the open, but in any case he would do well to beware before accepting the shelter of a cavern, for there he might encounter the terrible cave bear, larger than any existing species, or an animal even still more terrible, no other than man himself."

The nearest vision we can obtain to the life which Palæolithic man led is afforded us by the Tasmanian natives, unhappily extinct in our own times, but representing while they lived the last remnant of the true Palæolithic races. At one time they had probably been distributed over the Old World: displaced everywhere by superior races they at length became confined to Australia and Tasmania, and from Australia they were driven by the existing aborigines of that continent, a race superior to themselves in craft and cruelty. It was reserved for the white man to complete their extermination. The Tasmanians[1] were of middle height; the colour of the skin was almost black, inclining to brown. The eyes were small and deep set under overhanging brows, the nose short and broad with very wide nostrils; the mouth big and the teeth larger than that of any other existing race. The hair was black and grew in corkscrew ringlets; and the men had beards and whiskers. On the border of the whiskers the hair grew in tufted pellets like peppercorns. They were hunters, but peaceful men. Their weapons were stone or wood: and the stone implements of which one was like the Palæolithic boucher were made by chipping flakes from the pthanite stone of Tasmania. They wore no

[1] The last survivor died in 1877.

clothes ; they had no houses ; they merely wandered from one place to another in search of food—of which they ate most kinds, except fish which they had no idea of catching —and protected themselves from the biting winds by rude screens of bark.

M. Rutot (who has in this the support of other prehistorians) has subdivided the earliest times of Palæolithic man into three stages, basing them principally on the character of the flints which the ancient men have left as traces of themselves. The Strepyian Age is the first. It is characterized by a flint shaped rather like a rough dagger.[1] The Strepyian men used coarse flint scrapers and chisels which are a little like the disputed Eoliths.

Classification of Races

After the Strepyian men came those of the Chellean Age: so-called because the flint implements characteristic of their time were found at Chellés on the banks of the Seine. This age is characterized by the introduction of a new implement to which Prof. Sollas has given the name of a boucher. Put your two hands together, palm to palm, and you will have a fair idea of the almond-shaped "boucher," except that it varies a good deal in size from two or three inches to ten inches. It has been called a pick and an axe, and described as leaf-shaped. It was probably used for various purposes, and it may have had a haft tied to it by thongs of hide or sinews, in order to make a formidable weapon. Other implements of the Chellean men are known ; they occur most commonly in river gravels, though some examples are known in caves.[2] But the "boucher" is found all over the world—from end to end of Africa, from Cairo to the Cape ; from west to east of Southern Asia, from

[1] M. Hugo Obermaier has disputed the genuineness of these daggers.

[2] Kent's Hole near Torquay has yielded some together with the teeth of the cave bear.

Palestine to Malacca; in North America and Canada, and in South America. In fact in one sense the Chellean "boucher" proves too much, for we cannot suppose that all mankind, all over the world, was at that time of the Chellean race; or that the "boucher" was characteristic of one epoch alone, the Chellean. Probably the idea of the "boucher" originated with some one people and slowly spread all over the world at one time or another.

The Chellean "boucher," to disclose another point of view, is succeeded by the Acheulean "boucher" (so-called from the village of St. Acheul), which is much flatter, not so thick and consequently lighter. It is more carefully made, and is not only a better finished but a more efficient implement. The Acheulean Age—we are assuming that there was one—refined similarly the scrapers and chisels. In this age it is presumed that the climate was growing colder. The Acheulean Age was succeeded in its turn by the Mousterian Age.[1] The men of this age still further refined the flint weapons; and to a certain extent the "boucher" seems to have dropped out of use; and the most characteristic implement of the Age is the Mousterian "point". The Mousterian point is from two to six inches in length and is often carefully retouched; the Mousterian scraper also is a finely worked implement.

We now begin to reach the horizons of the Upper Palæolithic Age, when the geography of Europe was changing, as the sea first advanced, then withdrew, advanced again, and finally withdrawing left the continent with its present coast lines. Leaving out of consideration finer subdivisions, the Upper Palæolithic is marked off into the epochs of the Solutrian and the Magdalenian men. Solutré, which gives its name to the first of these epochs, is in the Rhone valley to the north of Lyons; but remains of the Solutrian men are found in Europe in many places south of Russia. Their

[1] Called after the district by Le Moustier in Dordogne.

age brought with it an extraordinary advance in the arts. The flint weapons are almost as fine as those which are the handiwork of the later or Neolithic Stone Age; though their fineness and handicraft reaches up to a climax and then deteriorates as the close of the age approaches. There seems to have been a trade in the best implements, for a hoard of them, "laurel leaf and shouldered points,"[1] was found in the valley of the Loire which were made of a kind of flint not found in the neighbourhood. The Solutrians were great hunters. At Solutré itself, where the horse seems to have been a favourite food, the broken bones of these animals left as the refuse of many feasts were piled in a ridge a hundred yards long; and at Piedmont in Moravia where the mammoth seems to have been the chief victim, more than two thousand mammoth teeth were found heaped together. But the Solutrian men were also great artists, sculptors, painters, draughtsmen, and in the last twenty years a series of discoveries have brought to light whole picture galleries of the Solutrian Age. The caves of Altannia in Spain yielded the first discoveries (to Don Marcellano de Santualo) of paintings of great skill on the walls, and his discovery has been followed by so many confirmatory ones since that scepticism has dwindled to the vanishing point. Prof. Sollas compares these Solutrian paintings to those of the Bushmen of Africa. Some of the Bushmen drawings and paintings, "both monochrome and polychrome, recall in the closest manner the best efforts of Solutrian times". The Solutrian never represented the human form in his drawings; but he was a sculptor; and some of the figurines he left—of women in the nude—are of great realistic and technical merit. But the more interesting fact concerning them is that these figures most closely resemble the women of the Bushmen race. That the Solutrian race were in a distinct way related to the Bush-

[1] Sollas.

men is an inference which has the support of many prehistorians and is strengthened by the discovery of some of their remains at Mentoni. It is now believed that this negroid race extended over Spain, the south of France, Belgium and reached to Vienna. It is not likely that Solutrian Europe was inhabited solely by them. One may suppose that it pushed northwards from the Mediterranean and then under pressure from the alien population it met there was forced back to the south and was finally driven out.

There remain the Magdalenian men or Cromagnards.[1] They were called Magdalenian from the famous rock shelter of La Madeleine, where a beautifully engraved drawing of a mammoth on ivory was found, a drawing which in vigour and skill and that subtle attribute called artistic feeling is one of the wonderful things of the world. The Magdalenian men have left besides many other beautiful drawings of animals; and they were perhaps the culminating race of Palæolithic man. Some of the flint implements deteriorated in their day: but they invented new ones. Spear heads and arrow heads appear; and there is a hint in some of them that the makers understood the use of poisoned weapons. They understood the use of the needle; they probably used lamps; and they certainly used personal ornaments some of which bear a curious resemblance to those now used by Eskimo women. From other resemblances to Eskimo, many efforts were made to associate these two races—the race that has disappeared and the one that lingers to-day—but the evidence has always been open to suspicion. The caves of Grimaldi yielded six skeletons of the Magdalenian race in 1906, and showed them (as we have already said in the description of the Cromagnards) to be a tall, thin-nosed people, entirely unlike the Eskimo. But in 1888 a skeleton was found near Perigueux in the commune of Chancelade

[1] Cp. pp. 326, 327 *ante*.

(France), among Magdalenian surroundings, which was of a different race—a race of low stature, and large skull, and of bodily characteristics in general which "leave no reasonable doubt that it represents the remains of a veritable Eskimo, who lived in Southern France during the Magdalenian Age".

Neolithic Man

These were the last of the Palæolithic races. Their successors in Europe at any rate were the Neolithic folk who brought with them a pastoral or agricultural mode of life. It is not possible to suppose other than that they were in existence before they pushed into Magdalenian territory. It is conceivable that with the retreat of the glaciers, Magdalenian man may have gone farther north in pursuit of the reindeer, and possibly may have found his way to the North American Continent by the Icelandic bridge, or by the Bering Strait—if the Icelandic bridge had ceased to exist. Sollas offers the speculation that in the Magdalenian Age two races of people differing greatly in stature stretched from Western Europe across the entire breadth of Asia. They both had arrived at what we may call the Magdalenian state of culture. The taller, stronger race of hunters held the South in comfort; the shorter race hemmed in by their tall relations to the south and by the ice to the north had to do the best they could and may have developed in consequence of hardship. As the climate became warmer the pressure of the multiplying pastoral people, pushing westwards from between the Carpathians and India, made itself felt and pushed the last Palæolithic races northwards and towards Bering Strait. The primitive Eskimo stayed along the coast; the other race may have extended through the length and breadth of the western continents of the Americas. With the real stone axe, afterwards the polished stone axe, the Neolithic man enters on the scene.

Here we may come to an end of speculation, for the

subsequent history of the human race is of a complexity which continually increases. Happily a wiser and more humane understanding of the rights as well as of the interest of existing primitive races has replaced the old indifference and inhumanity which helped to extinguish the Tasmanians —who were the last remaining representatives of a race perhaps as old as Neanderthal man, and the Bushmen, the probable representatives of the Mousterians or mid-Palæolithic men.

The Future of the Planet

A few concluding lines may be given to the question of the future of the planet, which in many of its external aspects has passed, and perhaps is destined to pass more completely, under the dominion of the latest race to inhabit it. The fear that the end of the world, or the end of life on the world, will come by fire or water has diminished. It is not theoretically impossible that the planet's life should be in jeopardy from volcanic and seismic convulsions; but they really offer no serious menace and they never appear to have done so in past ages. On a similar basis of reasoning we may assume that the planet will never be overwhelmed by its oceans; though as Suess points out, if the subsidences in the Atlantic in geologic time have actually been produced by an effort to establish planetary equilibrium, and, if there were further a remote tendency on the part of the planet to contract in order to establish a new radius—then we should have to fear a progressive diminution of the area which is inhabitable by the higher life of the land. We may offset this view against that which threatens the planet with a gradual diminution of its waters. We need only repeat with regard to that, the opinion of every geologist from Suess to Geikie and Chamberlin and Salisbury, that there have been periods in geologic history when deserts were as widespread as now, and that in mid-geologic history,

in the time of the Permian, there was an even greater aridity than prevails to-day. The geologic record points to the slow swinging oscillation of conditions. As there have been periods of greater aridity than now, so also there have been periods equally long when both the rainfall and the humidity have been more marked.

The danger to the race, if danger there be, lies not in boisterous catastrophes but in the deadly unbalancing of agencies of the quiet sort. For example, a small proportion of carbon dioxide in the atmosphere is necessary to plant life and to animal life, while a large proportion would be fatal to air-breathing animals. If the three or four hundredths of one per cent now present were lost all life would go with it; if it were increased to a few per cent the higher animal life would be suppressed or radically changed. On the planet the agencies both of supply and demand are abundant; we can only come to the conclusion that ever since the birth of air-breathing life some 40,000,000 years ago, the interplay of these agencies has been so balanced that neither fatal excess nor fatal deficiency has been permitted to cut short the history of the higher life.

In an equally serious way the habitability of the Earth depends on a narrow range of mean temperature, a range of some 100° C. A few miles above the planet and at a few miles below its surface the temperature would be disastrous to life. The necessary heat is dependent on the Sun, but the control of it, so far as life on the planet's surface is affected, is intimately related to the atmosphere, and to the blanketing capabilities of the atmosphere. These again depend on its constituents; and here again we have an indication of the critical balance in which the atmosphere holds life.

The planet's atmosphere is itself in a state of balance. The molecules of which its gases are constituted are perpetually flying at great speeds, and those which are flying at the

highest speeds must sometimes escape beyond the atmosphere's outer rim into interplanetary space. But if this idea of flying molecules be pushed to its logical conclusions, then we have to think of the Sun with a great atmosphere of a related kind, a far greater atmosphere than that of any of its planets; and we must think of its outer layers of thinner and thinner assemblages of molecules, as reaching far out towards its satellites. The Earth's atmosphere, its thinnest outermost assemblages of molecules, ceases only when these molecules pass beyond the reach of the Earth's gravitation. That is true also of the Sun's more remote atmospheric molecules—they cease to belong to the Sun only when they pass out of reach of the Sun's gravitation. But the Earth is easily within reach of the Sun's gravitation; so that we may conceive our planet as lying within the farther-flung thin extensions of the Sun's atmosphere. The Earth therefore, though it is constantly parting with its own swifter flying molecules, is continually catching and holding molecules derived from the Sun's atmosphere. The two atmospheres, the solar and the planetary, must be interchanging molecules at rates dependent on the conditions of equilibrium between them. The failure of our atmospheric supply is thus made to hang, not simply on the losses and gains at the Earth's surface, but on the solar interchange and hence on solar endurance.

With the life of the Sun that of the planet is bound up; for from the Sun the energies of the planet are derived, and on their continuance the life of the planet depends. The newer views of the inter-atomic energies, and the sources of energy on which the Sun can consequently draw have in theory raised the forecast of the Sun's power to an indeterminate order of magnitude and the length of its life to an indeterminate extent. The possibilities of a collision were reviewed in the earliest chapter of the planet's history, in describing the possibilities of the manner of its birth. As there was

a beginning so also there must be an end, though we may believe it to be indeterminately distant.

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